Scientific Excellence • Resource Protection & Conservation • Benefits for Canadians
Excellence scientifique • Protection et conservation des ressources • Bénéfices aux Canadiens

# Environmental Monitoring Report for the Point Lepreau, N.B. Nuclear Generating Station – 1985, 1986

R.W.P. Nelson, K.M. Ellis and J.N. Smith

Physical and Chemical Sciences Branch
Scotia-Fundy Region
Department of Fisheries and Oceans

Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
Canada B2Y 4A2

July 1988

## Canadian Technical Report of Hydrography and Ocean Sciences
## No. 107

Fisheries and Oceans    Pêches et Océans

Canada

## Canadian Technical Report of Hydrography and Ocean Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. The subject matter is related generally to programs and interests of the Ocean Science and Surveys (OSS) sector of the Department of Fisheries and Oceans.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out of stock reports will be supplied for a fee by commercial agents.

Regional and headquarters establishments of Ocean Science and Surveys ceased publication of their various report series as of December 1981. A complete listing of these publications is published in the *Canadian Journal of Fisheries and Aquatic Sciences*, Volume 39: Index to Publications 1982. The current series, which begins with report number 1, was initiated in January 1982.

## Rapport technique canadien sur l'hydrographie et les sciences océaniques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Le sujet est généralement lié aux programmes et intérêts du service des Sciences et levés océaniques (SLO) du ministère des Pêches et des Océans.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Les établissements des Sciences et levés océaniques dans les régions et à l'administration centrale ont cessé de publier leurs diverses séries de rapports en décembre 1981. Une liste complète de ces publications figure dans le volume 39, Index des publications 1982 du *Journal canadien des sciences halieutiques et aquatiques*. La série actuelle a commencé avec la publication du rapport numéro 1 en janvier 1982.

Canadian Technical Report of

Hydrography and Ocean Sciences No. 107

July 1988

# ENVIRONMENTAL MONITORING REPORT FOR THE POINT LEPREAU, N.B., NUCLEAR GENERATING STATION - 1985, 1986

by

R.W.P. Nelson, K.M. Ellis and J.N. Smith

Atlantic Environmental Radiation Unit

Physical and Chemical Sciences Branch
Scotia-Fundy Region
Department of Fisheries and Oceans

Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
Canada B2Y 4A2

90-05156/

© Minister of Supply and Services 1988

Cat. No. Fs 97-18/107E ISSN 0711-6764

Correct citation for this publication:

Nelson, R.W.P., K.M. Ellis, and J.N. Smith. 1988. Environmental monitoring report for the Point Lepreau, N.B. Nuclear Generating Station - 1985, 1986. Can. Tech. Rep. Hydrogr. Ocean Sci. No. 107: vi + 175 pp.

## ABSTRACT

Nelson, R.W.P., K.M. Ellis, and J.N. Smith. 1988. Environmental monitoring report for the Point Lepreau, N.B. Nuclear Generating Station - 1985, 1986. Can. Tech. Rep. Hydrogr. Ocean Sci. No. 107: vi + 175 pp.

The Point Lepreau Environmental Monitoring Program (PLEMP) has been established within the Department of Fisheries and Oceans to assess the environmental impact of radioactive, thermal and chemical releases from the Point Lepreau, N.B., Nuclear Generating Station (NGS) located on the Bay of Fundy. This report contains the results for the third and fourth years of the operational phase of the monitoring program. Emphasis has been placed on those areas where effects from the operation of the NGS were expected to be observed. Special emphasis was placed on the characterization of the thermal plume, the distribution of tritium within different phases of the environment and the uptake of radionuclides in lichen, an efficient accumulator of atmospheric particulates. Radionuclide measurements made on samples collected during the operational phase of the reactor have been compared to pre-operational activities to assess the impact of the operation of the NGS. The purpose of this program is to provide government with a comprehensive scientific basis upon which to assess the environmental implications of the operation of nuclear reactors in coastal regions and to determine various parameters associated with the longterm transport of radionuclides.

This report also includes AERU responses to two separate incidents which took place during 1985/86. The first was a boiler tube leak at the Point Lepreau NGS starting in December 1985. A field survey was undertaken in February of 1986 to assess the environmental impact of the leak on the environment in the general vicinity of the reactor. The second was the accident at the nuclear power station in Chernobyl, USSR. Samples were collected at various locations in the Atlantic region to assess the regional environmental impact of the Chernobyl accident.

## RÉSUMÉ

Nelson, R.W.P., K.M. Ellis, and J.N. Smith. 1988. Environmental monitoring report for the Point Lepreau, N.B. Nuclear Generating Station - 1985, 1986. Can. Tech. Rep. Hydrogr. Ocean Sci. No. 107: vi + 175 pp.

Le ministère des Pêches et Océans a mis sur pied le programme de surveillance de l'environnement de Pointe Lepreau pour évaluer les incidences sur le milieu des émissions de substances radioactives et chimiques et d'eau chaude de la centrale nucléaire de Pointe Lepreau (Nouveau-Brunswick), dans la baie de Fundy. Ce rapport donne les résultats du programme pour la troisième et la quatrième année de sa mise en oeuvre. Les endroits où nous courions les meilleures chances d'observer les effets éventuels de l'exploitation de la centrale ont fait l'objet d'une attention particulière. Ainsi, nous effectuons l'échantillonnage biologique dans les environs immédiats de la centrale. Par ailleurs, nous avons étudié de façon approfondie les caractéristiques du panache d'eau chaude, la dispersion du tritium dans l'environnement et la répartition des radionucléïdes dans les lichens car ces derniers captent et absorbent remarquablement bien les particules en suspension dans l'atmosphère. De plus, nous avons mesuré la présence de radionucléïdes dans les échantillons issus des principaux endroits où ils tendent à s'accumuler depuis la mise en exploitation de la centrale et nous les avons comparé aux niveaux enregistrés avant la période d'exploitation active pour en déterminer l'incidence sur le milieu. En outre, ce rapport fait état des mesures prises par la sous-section de radioprotection de l'Atlantique (AERU) en réaction à deux incidents distincts qui se sont produits en 1985-1986. En décembre 1985, l'un des tubes du réacteur de la centrale de Pointe Lepreau s'est mis à fuir. Dès février 1986, une étude sur le terrain a été

entreprise pour évaluer les retombées écologiques de la fuite dans les environs immédiats de la centrale. Le second incident, c'est l'explosion de la centrale de Chernobyl en URSS. Des échantillons ont été pr levés à divers endroits dans la région de l'Atlantique pour déterminer l'impact de la catastrophe sur nos côtes. Le programme de surveillance de l'environnement de Pointe Lepreau a pour but de fournir au gouvernement toutes les informations scientifiques nécessaires pour qu'il soit en mesure d'évaluer les conséquences écologiques de l'exploitation de centrales nucliaires dans les zones côtières.

## TABLE OF CONTENTS

Page

1.0 INTRODUCTION .......... 1

2.0 MARINE ENVIRONMENT .......... 4

2.1 Water Circulation .......... 4

2.2 Effluent Releases .......... 9

2.3 Chemical Oceanography .......... 9

2.3.1 Radionuclides in the Water Column .......... 12

2.3.1.1 Cs-137 Activity in Seawater .......... 12

2.3.1.2 Gamma Emitting Radionuclides in Seawater .......... 19

2.3.1.3 Plutonium in Seawater .......... 19

2.3.1.4 Tritium in Seawater .......... 23

2.3.2 Nutrients .......... 23

2.4 Thermal Plume Study .......... 24

2.4.1 Thermal Plume Field Work .......... 24

3.0 ATMOSPHERIC MONITORING .......... 59

3.1 Meteorological Data Collection .......... 59

3.2 Air Monitoring Results .......... 60

3.2.1 Tritium Results .......... 66

3.2.2 Radionuclides in Atmospheric Particles .......... 79

3.2.2.1 Beryllium-7 .......... 79

4.0 THE MARINE ENVIRONMENT .......... 82

4.1 Radionuclide Concentration Processes .......... 82

4.2 Sampling, Sample Processing and Analysis .......... 83

4.3 Marine Algae .......... 84

4.4 Marine Animals .......... 88

4.5 Tritium in Marine Organisms .......... 89

5.0 AQUATIC AND TERRESTRIAL ENVIRONMENTAL PHASES ........ 94

- 5.1 Aquatic Systems ........ 94
  - 5.1.1 Water Column Results ........ 96
  - 5.1.2 Aquatic Plants and Animals ........ 98
- 5.2 Terrestrial Systems ........ 101
  - 5.2.1 Terrestrial Plants ........ 101
  - 5.2.2 Birds ........ 109
- 5.3 Tritium in Aquatic and Terrestrial Systems ........ 111

6.0 POINT LEPREAU LEAK SURVEY ........ 115

7.0 CHERNOBYL STUDY ........ 120

- 7.1 Introduction ........ 120
- 7.2 Air Monitoring ........ 121
  - 7.2.1 Sampling ........ 121
  - 7.2.2 Air Results ........ 123
  - 7.2.3 Rainfall Results ........ 138
- 7.3 Biological Oceanography ........ 138
- 7.4 Terrestrial Environment ........ 142
  - 7.4.1 Milk ........ 143
  - 7.4.2 Plants ........ 145
- 7.5 Aquatic Plants and Animals ........ 156
- 7.6 Plutonium ........ 156
- 7.7 Conclusions ........ 159

8.0 LABORATORY INTERCOMPARISON STUDY ........ 161

9.0 CONCLUSIONS ........ 163

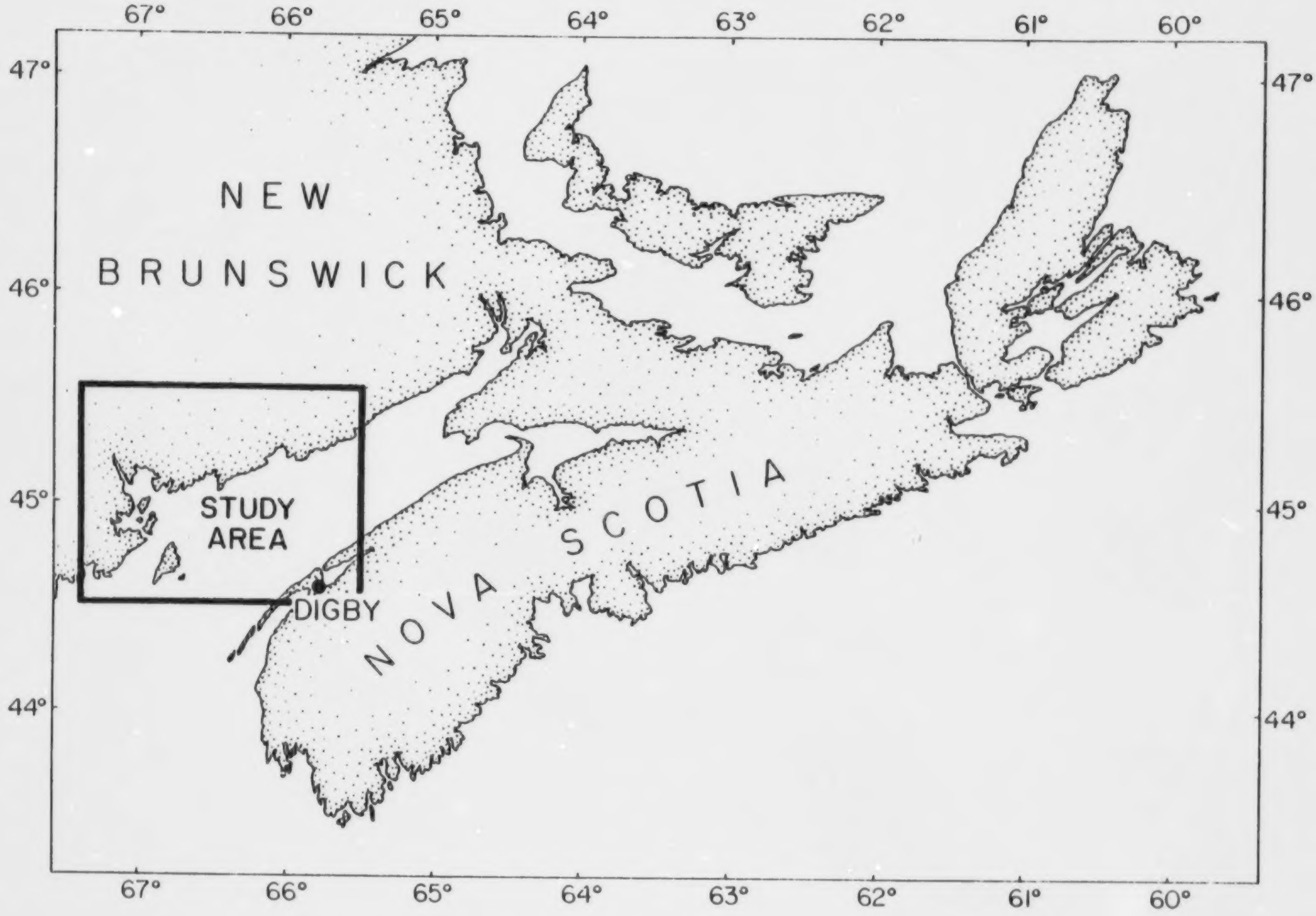
## 1.0. INTRODUCTION

The Point Lepreau Environmental Monitoring Program (PLEMP) was established in 1978 to assess the impact of the operation of the CANDU 600 nuclear reactor built at Point Lepreau on the shores of the Bay of Fundy (Figure 1). PLEMP was designed to provide a broad understanding of the distribution processes affecting radioactivity released from the NGS into the surrounding environment. The sampling program, which includes the major environmental reservoirs and measurement of key oceanographic parameters, has been used to identify transport pathways for radionuclides through various environmental media and to determine fluxes of radionuclides along specific pathways.

The responsibility for initializing and maintaining PLEMP has been assigned to the Atlantic Environmental Radiation Unit (AERU), which is a section of the Marine Chemistry Division, Physical and Chemical Sciences Branch, Department of Fisheries and Oceans, Scotia Fundy Region located at the Bedford Institute of Oceanography, Dartmouth, Nova Scotia. In addition, a working group on environmental radioactivity, composed of scientists in various disciplines (Appendix 1) has been established as a resource and advisory group for PLEMP.

PLEMP has been carried out in two phases. The pre-operational program began in 1979 and continued through 1982 when the Point Lepreau reactor became operational. Results are summarized in Bishop *et al.* (1980), Smith *et al.* (1981, 1982) and Ellis *et al.* (1984).

The results for the first two years of the operational program are summarized in Nelson *et al.* (1985, 1986). These results have been utilized to focus PLEMP on those components of the environment for which impacts from the operation of the NGS were most evident. Sample collection in 1985 and 1986 focused on the immediate vicinity of the Point Lepreau peninsula. Special effort has also been directed toward the thermal plume, tritium in the biosphere, and radionuclide levels in lichen, a known accumulator of atmospheric particulate material.



67°
66°
65°
64°
63°
62°
61°
60°
47°
46°
45°
44°
NEW BRUNSWICK
NOVA SCOTIA
STUDY AREA
DIGBY

Figure 1. Location of the Point Lepreau study area in the Bay of Fundy.

In addition, two events took place in 1986 of direct concern to PLEMP. The first, a small leak of heavy water (containing tritium and other radionuclides) in a boiler tube in the reactor core which occurred in late December 1985 and continued until April, 1986 resulted in elevated releases of tritium in liquid and gaseous form. The relatively constant effluent release of tritium represented a unique opportunity to study the behaviour of tritium in the Bay of Fundy and to determine its steady state distribution in the thermal plume. Tritium levels were measured in water and biota, in marine and terrestrial samples and in atmospheric water vapour collected during the period of the leak and the effect of the leak on the environment was assessed.

The other event of major significance was the accident which took place at the Chernobyl nuclear power station in the USSR on April 26, 1986. As a consequence of the accident at Chernobyl, large quantities of radioactivity were released to the atmosphere and heat generated both by the reactor core and the fire in the graphite moderator caused the plume to rise up several thousand meters, resulting in world wide deposition of radioactivity. In order to characterize the deposition of Chernobyl fallout products in the Point Lepreau area and to differentiate this fallout from reactor releases, the sampling program was expanded somewhat in the summer of 1986. This expansion involved increasing sampling at Point Lepreau and the collection of plants, etc., at the Bedford Institute of Oceanography (B.I.O.). In addition, some analyses of food, including milk, was carried out in response to requests from the Radiation Protection Bureau (RPB) of Health and Welfare Canada. The measurements of Chernobyl fallout products provided an excellent opportunity to test the accuracy and precision of different components of PLEMP.

## 2.0 MARINE ENVIRONMENT

### 2.1 Water Circulation

Water circulation patterns in the Bay of Fundy are dominated by a cyclonic, anticlockwise gyre with inflow along the coast of Nova Scotia and outflow along the New Brunswick coast passing to the east of Grand Manan Island (Bumpus and Lauzier, 1965). Water mass relationships in the Bay of Fundy are characteristic of simple estuarine circulation. Low salinity water dominated by inputs from the Saint John River (from which up to 60% of the freshwater input originates) flows out at the surface, while denser shelf and slope waters mix across the shelf break and enter the Bay of Fundy at depths predominantly below 100 meters.

Salinity-depth profiles have been constructed along a series of three transects (Figure 2). The transects were chosen to approximate those used on previous cruises, to help illustrate the predominant characteristics of water circulation in the Point Lepreau area during the winter season.

Cruise 85-041 (December, 1985) was the first early winter cruise undertaken during the program in which salinity-depth profiles were measured. In Figure 3, the salinity-depth profile for transect A indicates the presence of the freshwater plume at Station 1 to be well offshore and to the east of Grand Manan Island. A strong influence of freshwater input is observed at Station 6 at the mouth of Passamaquoddy Bay, that probably originates from the St. Croix River. Transect B, (Figure 4) shows the influence of freshwater input from the Saint John River as far away as Station 45 and indicates that the plume moves offshore past this point. Transect C, (Figure 5) confirms this pattern and illustrates the pathway of the freshwater plume offshore out of the Bay of Fundy to the east of Grand Manan Island. These three salinity-depth diagrams show that in the winter season, the magnitude of freshwater input is lessened and that the freshwater plume does not influence the area of the cooling water outflow, but rather stays offshore as it travels out of the Bay of Fundy.

In general, water circulation patterns in the Bay of Fundy are seasonal in nature and are influenced by the magnitude of freshwater input. The major source of freshwater runoff is from the Saint John River and the freshwater plume moves along the coast of N.B. at varying distances offshore and then splits around Grand Manan Island as it exits the Bay of Fundy. The winter is a

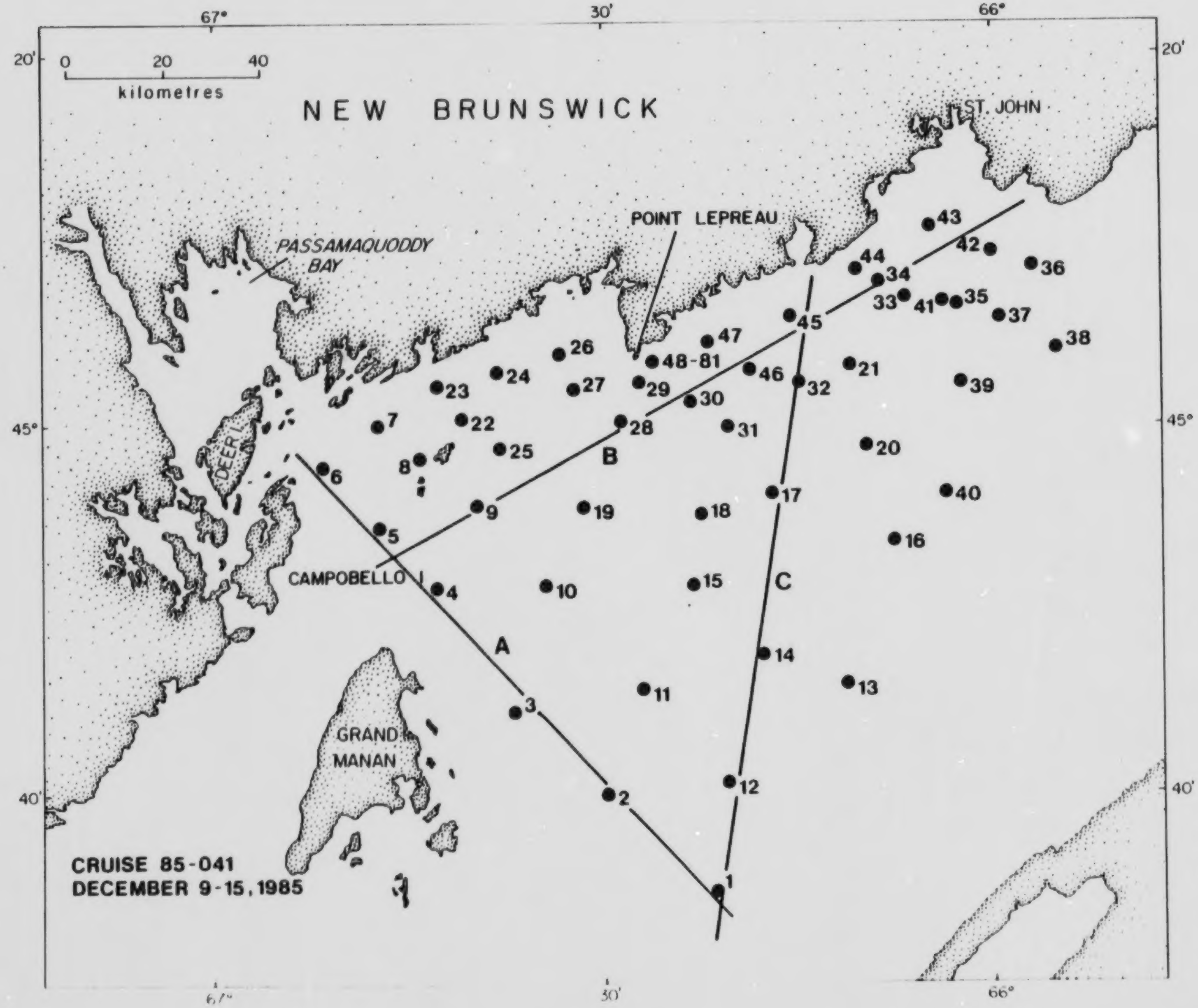

67°
30'
66°
20'
45°
40'
0
20
40
kilometres
NEW BRUNSWICK
ST. JOHN
POINT LEPREAU
PASSAMAQUODDY BAY
DEER I.
CAMPOBELLO I.
GRAND MANAN
A
B
C
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48-81
CRUISE 85-041
DECEMBER 9-15, 1985

Figure 2. Station locations for cruise 85-041 and transect lines used for salinity depth profiles shown in Figures 3, 4 and 5.

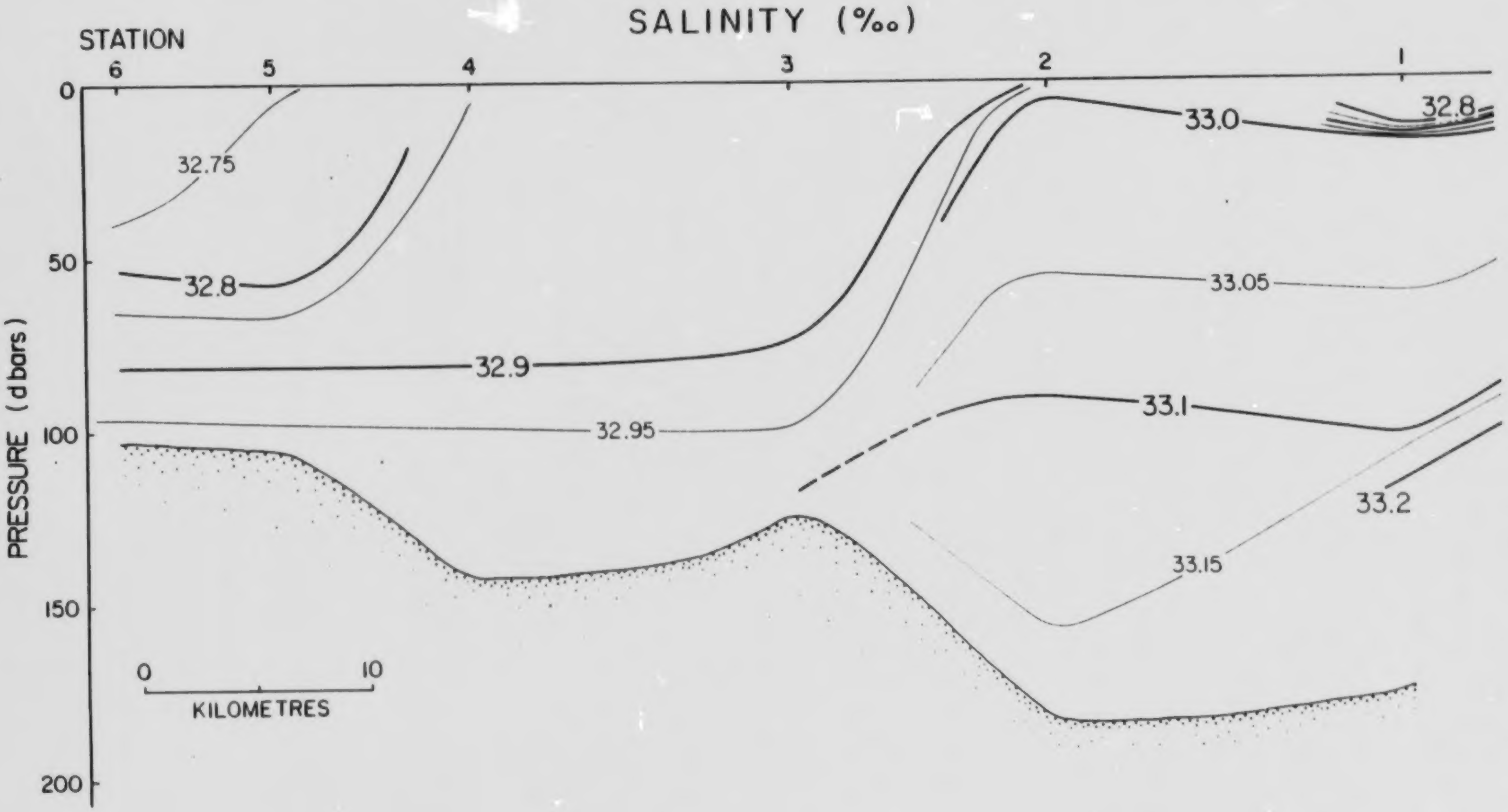


Figure 3 Salinity depth profile for transect a, shown in Figure 2, (1 dbar is approximately 1 meter)

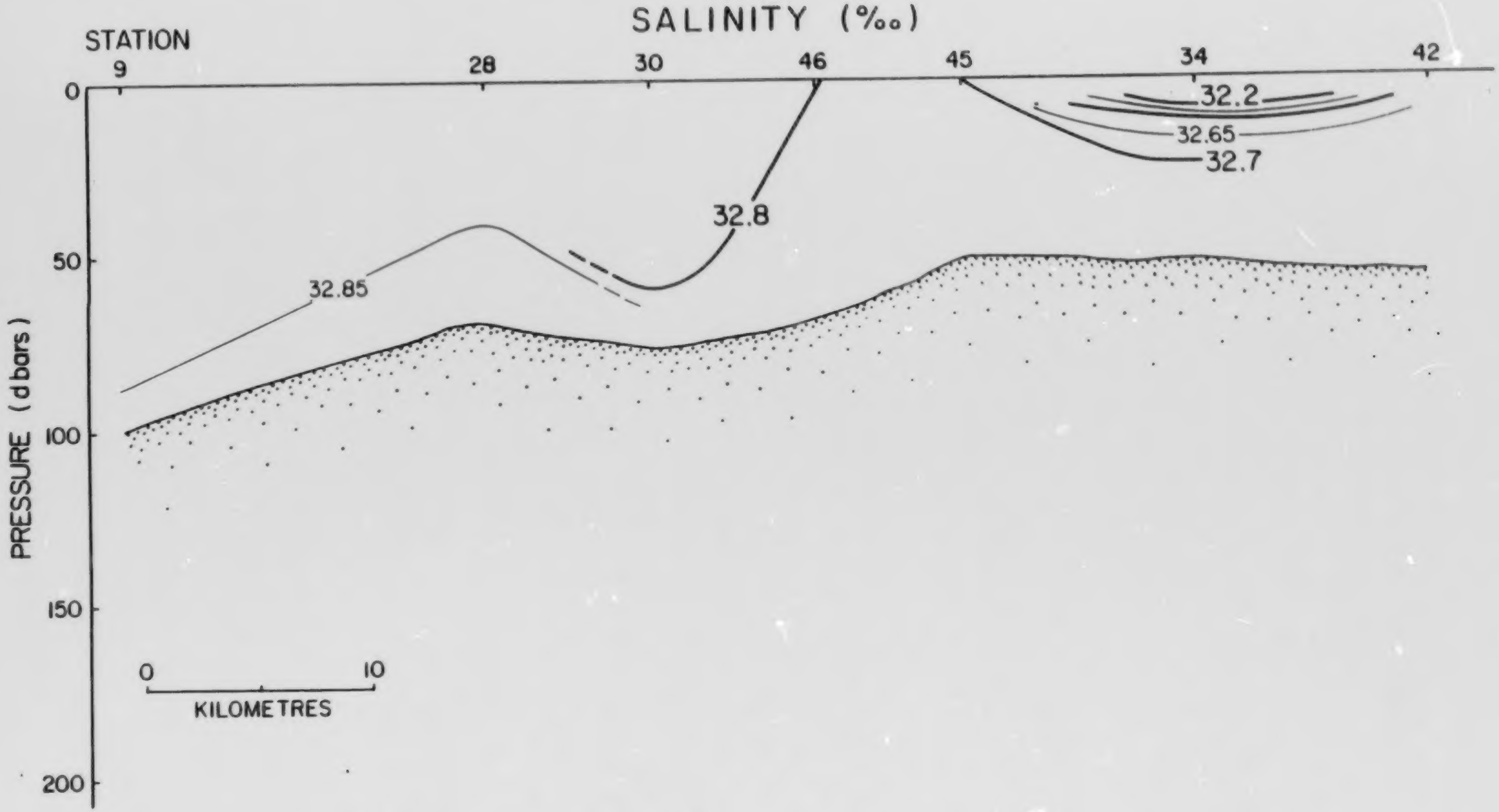


Figure 4 Salinity depth profile for transect b, shown in Figure 2

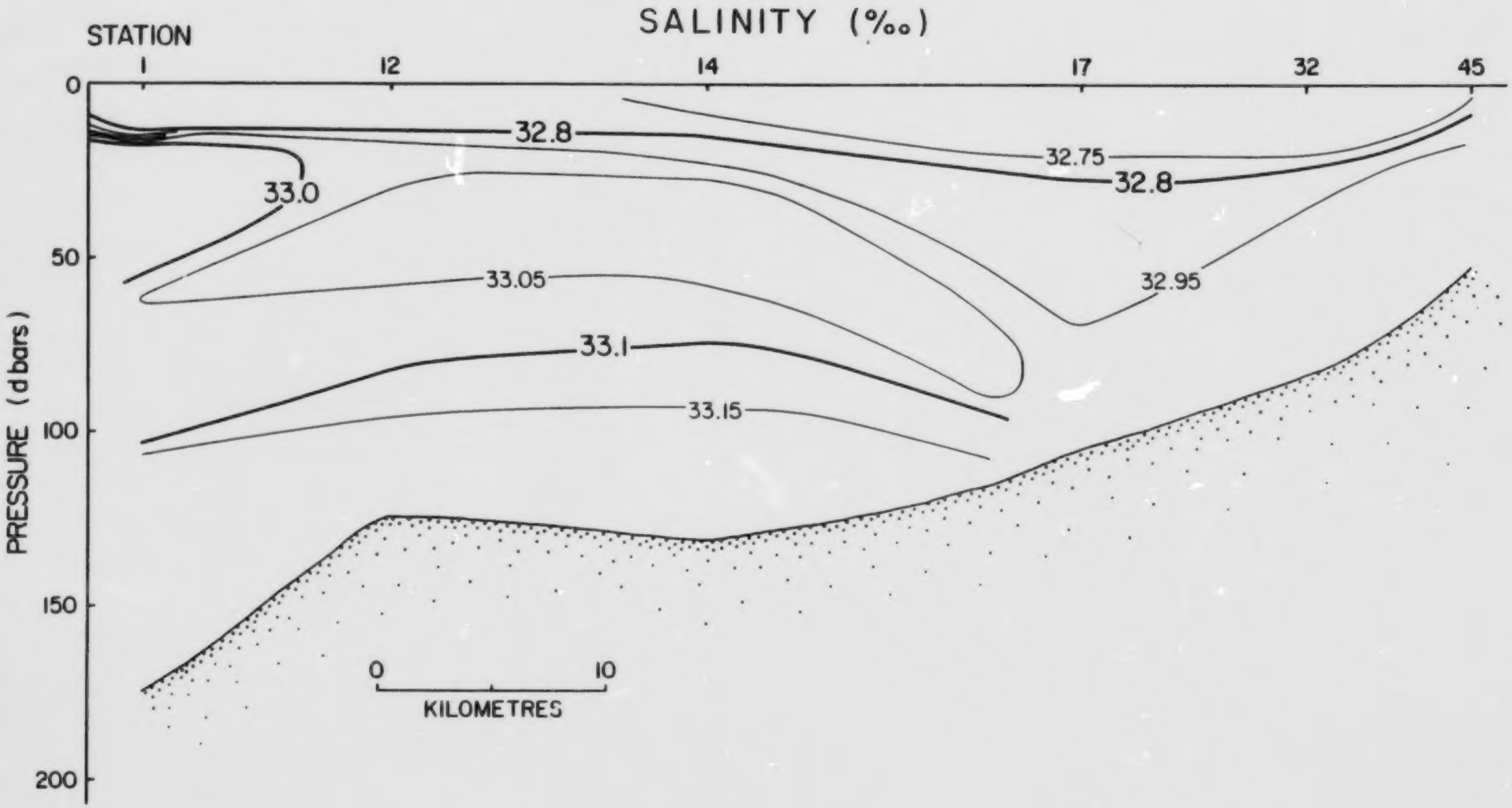


Figure 5. Salinity depth profile for transect c, shown in Figure 2.

time of reduced freshwater input when the freshwater plume moves offshore as it enters the Bay of Fundy along transect C and exits the Bay of Fundy east of Grand Manan Island. The spring is a time of high river runoff and increased stratification and reduced vertical mixing. Freshwater input is reduced during the summer when vertical mixing is not inhibited by the thick freshwater surface layer present at times of high river runoff. The prevailing circulation patterns in the Bay of Fundy are dependent on the magnitude and duration of freshwater input from the spring melt.

## 2.2 Effluent Releases

The release of radioactive materials to the environment is an inevitable consequence of the use of nuclear energy. Radionuclides may be discharged or released to either the atmosphere or the marine environment as a result of various processes involved in the production of nuclear power, (e.g. neutron activation of reactor support and encasement material creating activation products).

Emissions from the Point Lepreau NGS to the marine environment are closely monitored at the source under the mandate of the Liquid Effluent Monitoring Program (LEM) conducted by the New Brunswick Electric Power Commission (NBEPC). The liquid effluent monthly summaries for 1985 and '86 are presented in Table 1A and 1B (NBEPC 1985, 1986). Releases are reported as a percent of the Derived Emission Limit (DEL) that has been calculated for each radionuclide. The total activity released per year (excluding tritium) has decreased each year since 1983.

## 2.3 Chemical Oceanography

The chemical oceanography program of PLEMP was designed to help characterize the general water column chemistry of the western Bay of Fundy and establish baseline levels of radionuclides and their analogues to aid in the prediction of the transport characteristics of radionuclide releases from the Point Lepreau NGS. The operational phase of PLEMP

Table 1A. Liquid effluent monthly summary for 1985 from the Point Lepreau NGS.

| Analysis | Monthly DEL (Bq) | % Monthly DEL | | | | | | | | | | | | Total Bq Released 1985 | Average % DEL to Date |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | | |
| H-3 | 4E+18 | 4E-05 | 8E-06 | 4E-05 | 1E-05 | 5E-05 | 2E-05 | 3E-05 | 3E-05 | 8E-05 | 8E-05 | 5E-05 | 2E-04 | 2.4E+13 | 5.1E-05 |
| Cr-51 | 2E+15 | -- | -- | -- | -- | -- | 2E-07 | 2E-07 | -- | -- | -- | 1E-06 | -- | 2.8E+07 | 1.2E-07 |
| Mn-54 | 2E+13 | 3E-07 | -- | -- | -- | -- | 8E-07 | 2E-06 | -- | -- | -- | -- | 4E-06 | 1.7E+06 | 6.0E-07 |
| Co-58 | 7E+13 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Fe-59 | 1E+13 | -- | -- | -- | -- | -- | -- | 2E-05 | -- | -- | -- | -- | -- | 1.9E+06 | 1.6E-06 |
| Co-60 | 3E+13 | -- | 1E-06 | -- | -- | 2E-06 | 2E-06 | 2E-06 | -- | 3E-07 | -- | 8E-07 | 4E-05 | 1.3E+07 | 4.1E-06 |
| Zn-65 | 9E+12 | 2E-06 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2.0E+05 | 1.8E-07 |
| Sr-90 | 2E+14 | 5E-10 | 3E-10 | 5E-10 | 2E-10 | 2E-10 | -- | -- | -- | 5E-10 | 1E-09 | 3E-10 | 1E-09 | 9.0E+05 | 3.8E-10 |
| Zr-95 | 6E+13 | 1E-06 | 5E-05 | 1E-05 | 2E-06 | 4E-06 | 6E-06 | 6E-06 | 9E-06 | 2E-05 | 4E-06 | 6E-05 | 3E-05 | 1.2E+08 | 1.7E-05 |
| Nb-95 | 6E+13 | 3E-06 | 8E-05 | 2E-05 | 7E-06 | 1E-05 | 1E-05 | 1E-05 | 2E-05 | 3E-05 | 8E-06 | 9E-05 | 5E-05 | 2.1E+08 | 2.9E-05 |
| Ru-103 | 1E+14 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 3E-06 | 2E-06 | 5.5E+06 | 4.2E-07 |
| Ru-106 | 2E+13 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Ag-110M | 1E+13 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 5E-06 | -- | 6.2E+05 | 4.0E-07 |
| I-131 | 1E+13 | -- | 1E-04 | 3E-06 | -- | 1E-06 | -- | -- | -- | -- | -- | 6E-03 | 3E-03 | 1.2E+09 | 8.2E-04 |
| Cs-134 | 4E+13 | -- | -- | -- | -- | -- | -- | -- | | -- | -- | 8E-07 | -- | 3.3E+05 | 6.7E-08 |
| Cs-137 | 7E+13 | 1E-06 | 2E-07 | 3E-06 | -- | 2E-06 | 4E-07 | 1E-06 | -- | 1E-07 | -- | 2E-06 | 3E-07 | 6.3E+06 | 7.9E-07 |
| Ba-140 | 2E+14 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Ce-141 | 2E+14 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Ce-144 | 2E+13 | -- | -- | -- | -- | 6E-06 | -- | -- | -- | -- | -- | -- | -- | 1.3E+06 | 5.4E-07 |
| Activity Released (Excluding H-3) | | 4E-5 | 2E-4 | 9E-5 | 5E-4 | 9E-4 | 9E-5 | 1E-4 | 1E-3 | 9E-6 | 3E-5 | 2E-5 | 2E-6 | 1.6E+9 | 8.8E-4 |

Average Emission Rate (all nuclides) . . . 9.3E-04% DEL

This table lists releases of isotopes for which a DEL has been calculated.

Table 1B. Liquid effluent monthly summary for 1986 from the Point Lepreau NGS.

| Analysis | Monthly DEL (Bq) | % Monthly DEL | | | | | | | | | | | | Total Bq Released 1986 | Average % DEL to Date |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | | |
| H-3 | 4E+18 | 7E-4 | 3E-4 | 1E-4 | 5E-4 | 2E-4 | 6E-5 | 1E-4 | 6E-4 | 1E-4 | 3E-5 | 2E-5 | 3E-5 | 1.1E+14 | 2.3E-04 |
| Cr-51 | 2E+15 | -- | -- | 7E-8 | -- | -- | -- | -- | 1E-6 | -- | 5E-8 | -- | -- | 2.2E+07 | 9.0E-08 |
| Mn-54 | 2E+13 | 3E-5 | 7E-6 | 2E-6 | 2E-5 | -- | -- | -- | 4E-5 | -- | -- | -- | -- | 2.4E+07 | 8.3E-06 |
| Co-58 | 7E+13 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Fe-59 | 1E+13 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Co-60 | 3E+13 | 5E-6 | -- | 1E-6 | -- | 4E-6 | -- | 3E-6 | 1E-4 | -- | -- | 1E-5 | -- | 3.7E+07 | 1.2E-05 |
| Zn-65 | 9E+12 | -- | -- | -- | -- | -- | -- | -- | 9E-5 | -- | -- | -- | -- | 8.4E+06 | 7.5E-06 |
| Sr-90 | 2E+14 | 2E-8 | -- | 3E-8 | -- | 8E-8 | -- | 5E-8 | 4E-7 | -- | 3E-8 | -- | 2E-8 | 1.2E+06 | 5.1E-08 |
| Zr-95 | 6E+13 | 1E-5 | 1E-5 | 5E-5 | 1E-5 | 2E-4 | 3E-5 | 4E-5 | 2E-4 | 2E-6 | 1E-6 | 5E-7 | 3E-7 | 3.5E+08 | 4.8E-05 |
| Nb-95 | 6E+13 | 2E-5 | 2E-5 | 8E-5 | 2E-5 | 3E-4 | 6E-5 | 9E-5 | 4E-4 | 8E-6 | 6E-6 | 4E-6 | 1E-6 | 5.9E+08 | 8.2E-05 |
| Ru-103 | 1E+14 | -- | -- | -- | -- | 9E-8 | 1E-7 | -- | 1E-5 | -- | -- | -- | -- | 1.2E+07 | 9.1E-07 |
| Ru-106 | 2E+13 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Ag-110m | 1E+13 | -- | -- | -- | -- | -- | -- | -- | 6E-5 | -- | 2E-6 | -- | -- | 7.7E+06 | 4.9E-06 |
| I-131 | 1E+13 | 3E-4 | 9E-6 | 4E-5 | 3E-5 | 4E-6 | -- | -- | -- | -- | 6E-6 | -- | -- | 4.7E+07 | 3.3E-05 |
| Cs-134 | 4E+13 | -- | -- | -- | -- | -- | -- | -- | 2E-6 | -- | 3E-6 | -- | -- | 1.8E+06 | 3.7E-07 |
| Cs-137 | 7E+13 | -- | -- | 1E-7 | 7E-6 | 9E-7 | -- | -- | 2E-5 | -- | 1E-5 | -- | -- | 2.5E+07 | 3.1E-06 |
| Ba-140 | 2E+14 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Ce-141 | 2E+14 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Ce-144 | 2E+13 | -- | -- | -- | -- | -- | -- | -- | 2E-5 | -- | -- | -- | -- | 3.8E+06 | 1.6E-06 |
| Activity Released (Excluding H-3) | | 4E-4 | 4E-5 | 2E-4 | 9E-5 | 5E-4 | 9E-5 | 1E-4 | 1E-3 | 9E-6 | 3E-5 | 2E-5 | 2E-6 | 1.1E+9 | 2.0E-4 |

Average Emission Rate (all nuclides) . . . 9.3E-04% DEL

This Table lists releases of isotopes for which a DEL has been calculated.

continues to include the measurement of important hydrographic parameters including temperature, salinity, nutrients, and suspended particulate matter, and to monitor the levels of Cs-137, H-3, plutonium and gamma-emitting radionuclides both in the water column and sediments. The information collected in the operational phase of the program is compared to the pre-operational data base to assess anthropogenic releases of radioactivity during the operational program. In addition, information on water circulation patterns, dispersion rates and particle transport processes are being updated at seasonal intervals.

### 2.3.1 Radionuclides - Water Column

The December 1985 cruise 85-041 was the third in a series of operational cruises conducted by AERU. The seawater sampling procedures and the analytical methods used at the AERU laboratory are described elsewhere (Ellis *et al.* 1984). Briefly, 50 liter water samples were collected at surface and bottom water depths and the seawater samples were passed through columns consisting of: (1) a 0.3 micrometre pore size filter to remove particulates; (2) Chelex-100 ion exchange resin to adsorb activation products, such as Co-60 and Mn-54; and (3) a KCFC column (potassium cobalt ferrocyanide) that absorbs cesium (for Cs-137 and Cs-134) (Figure 6). Samples were also collected and analyzed for nutrients, salinity and tritium. In addition, thermal plume studies were undertaken to determine the effects, if any, of thermal releases from the Point Lepreau NGS. The sampling matrices and nuclear instrumentation used in this program are summarized in Table 2.

#### 2.3.1.1 Cs-137 Activity in Seawater

Cs-137 is a relatively long lived ($t_{\frac{1}{2}} = 30.2y$) fission product which originates mainly from nuclear weapons testing programs and nuclear power production. Cesium is present in seawater primarily as $Cs^{+1}$ and is expected to be found almost entirely in its dissolved ionic state (Coughtrey *et al.* 1983). In addition, it is one of the few fission products that is present in readily detectable quantities in the ocean today that will continue to be released from the NGS.

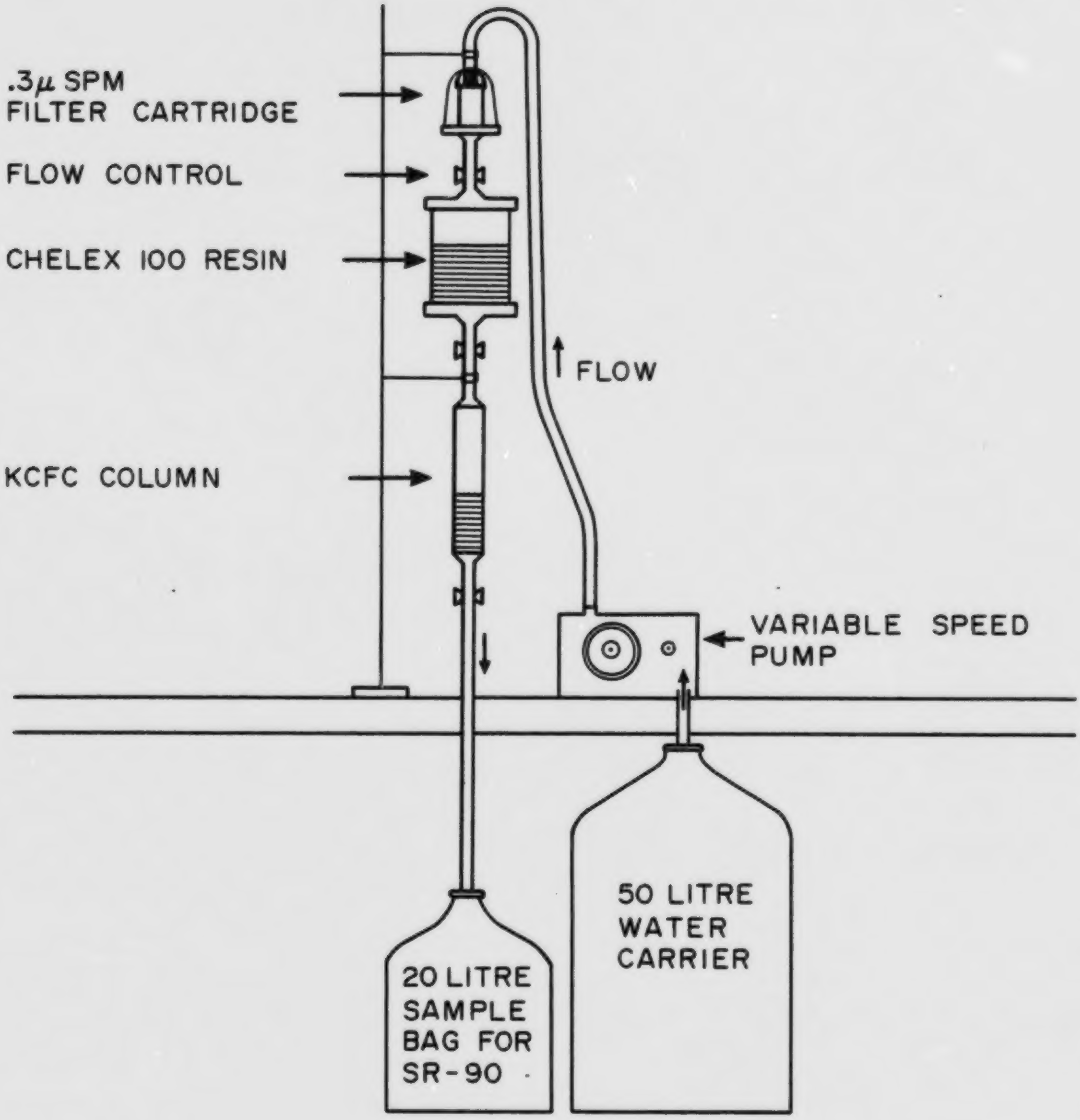

.3μ SPM
FILTER CARTRIDGE
FLOW CONTROL
CHELEX 100 RESIN
FLOW
KCFC COLUMN
VARIABLE SPEED PUMP
50 LITRE WATER CARRIER
20 LITRE SAMPLE BAG FOR SR-90

Figure 6. Schematic diagram of column used to concentrate radionuclides from seawater.

Table 2. Summary of nuclear instrumentation used in the AERU Laboratory.

| Nuclide | Environmental Phase | Counting Matrix | Detection System |
|---|---|---|---|
| Cs-137 | Seawater | KCFC | Ge and NaI Detectors |
| Cs-137 | SPM | Filter Cartridge (0.3 µm) | Ge Detector |
| Cs-137 | Sediment | Dried Bulk Sediment | Ge and NaI Detectors |
| Sr-90 | Seawater, SPM, and Sediment | Y-90 on Filter Paper | Alpha/Beta Counter |
| Gamma emitters | Seawater | Chelex-100 Eluate | Ge Detector |
| Gamma emitters | SPM | Filter Cartridge (0.3 µm) | Ge Detector |
| H-3 | Seawater | Gel (Water/Cocktail) | Liquid Scintillation Counter |
| Pb-210 (Po-210) | SPM, Sediments | Ag,Ni Discs | Alpha Spectrometer (Surface Barrier Detectors) |
| Pu-239,240 | Sediment | Steel Disc | Alpha Spectrometer |
| Ra-226 | Sediment | Ra-222 Gas | Gas Phase Scintillation Counter |
| Ra-226 | Sediment | Bi-214 in Dried Bulk Sediment | Ge Detector |

Cesium-137 activities measured in sea water samples collected during the winter 1985 cruise (Figure 2) are presented in Table 3. Samples were collected at nine locations (and at an anchor station where samples were collected at hourly intervals over a 36-hour time period), (stations 48-81). Activity measurements are reported in Becquerels (Bq), (1 Bq equals one disintegration per second). Conversion factors for other units of radioactivity are listed in Appendix 2. The mean Cs-137 activity measured for all stations (excluding the anchor station) was $3.15 \pm 0.42$ mBq/ℓ ($n = 20$). This is within the range of Cs-137 activities measured during the pre-operational phase (Table 4). There was no strong correlation observed between Cs-137 activity and water depth, geographical location or salinity. This observation is believed to be indicative of the efficient tidal mixing found in the Bay of Fundy.

Filter cartridges used to collect suspended particulate material (SPM) were analyzed for Cs-137 from a number of stations and depths. The distribution coefficient, $k_D$ for Cs-137, estimated from the following equation

$$k_D = \frac{\textit{Activity on particles } (Bq/g)}{\textit{Activity in solution } (Bq/ml)} \qquad (1)$$

is $3 \times 10^3$ with a range of $10^2$ to $2 \times 10^4$ (IAEA, 1985a). Levels of particulate Cs-137 were generally below the detection limit of 0.6 mBq/ℓ corresponding to less than 10% of the Cs-137 associated with particles and a $k_D$ of less than $5 \times 10^4$. Less than 5% of the total Cs-137 in seawater is expected to be associated with SPM (Kupferman *et al.* 1979).

As in previous cruises, a designated anchor station, located several hundred meters off the cooling water outfall at Point Lepreau (Figure 2), was occupied for a 36 hour period (Stations 48-81). Rosette casts were carried out every hour and samples were collected at surface and bottom water depths and analyzed for Cs-137, salinity and SPM. The results of these analysis are presented in Figure 7. Salinities measured were within 32.4 to 32.8‰ for both surface and bottom water samples indicating that the freshwater plume from the Saint John River was not a significant factor in the Point Lepreau area at this time of the year. SPM values for bottom water samples ranged from 1.8 to 26 mg/ℓ (average $9.2 \pm 7.4$) and surface waters ranged form 1.8 to 15 mg/ℓ (average $8.0 \pm 5.2$). SPM

Table 3. Soluble Cs-137, H-3, SPM and nutrient results for selected stations sampled during Cruise 85-041.

| SAMPLE | STATION # | DEPTH (m) | SALINITY ‰ | SILICATE (µg-AT/ℓ) | PHOSPHATE (µg-AT/ℓ) | NITRATE (µg-AT/ℓ) | SPM (mg/ℓ) | Cs-137 (mBq/ℓ) | H-3 (Bq/ℓ) |
|---|---|---|---|---|---|---|---|---|---|
| 85-2807 | 3 | 120 | 32.998 | 6.88 | 1.23 | 8.31 | 0.67 | 3.60 ± .55 | -- |
| 85-2808 | 3 | 57 | 32.896 | 6.33 | 1.43 | 8.10 | 0.33 | 3.77 ± .55 | -- |
| 85-2810 | 3 | 1 | 32.878 | 4.89 | 0.71 | 6.16 | 0.48 | 3.60 ± .55 | -- |
| 85-2817 | 6 | 93 | 32.843 | 8.60 | 0.96 | 9.96 | 0.98 | 3.06 ± .37 | -- |
| 85-2818 | 6 | 2 | 32.747 | 7.26 | 0.87 | 8.20 | 1.22 | 3.08 ± .62 | -- |
| 85-2852 | 19 | 66 | 32.874 | 7.46 | 0.91 | 9.10 | 1.42 | 2.95 ± .55 | -- |
| 85-2853 | 19 | 3 | 32.874 | 5.90 | 0.80 | 7.04 | 2.29 | 2.73 ± .53 | -- |
| 85-2859 | 23 | 46 | 32.810 | 8.40 | 1.00 | 9.73 | 1.13 | 3.37 ± .57 | -- |
| 85-2860 | 23 | 2 | 32.781 | 8.75 | 1.00 | 9.72 | 1.22 | 2.55 ± .63 | -- |
| 85-2865 | 26 | 23 | 32.724 | 9.54 | 1.02 | 10.80 | 2.74 | 3.55 ± .55 | -- |
| 85-2866 | 26 | 1 | 32.744 | 7.29 | 0.404 | 8.04 | 1.93 | 3.87 ± .83 | -- |
| 85-2877 | 32 | 80 | 32.874 | 6.24 | 0.89 | 8.10 | 1.41 | 3.07 ± .45 | -- |
| 85-2878 | 32 | 3 | 32.618 | 6.83 | 0.084 | 8.04 | 10.40 | 2.95 ± .60 | -- |
| 85-2881 | 34 | 40 | 32.717 | 7.60 | 0.98 | 9.10 | 8.42 | 2.66 ± .53 | -- |
| 85-2882 | 34 | 3 | 32.303 | 8.25 | 0.99 | 9.26 | 1.86 | 3.37 ± .55 | -- |
| 85-2896 | 41 | 72 | 32.835 | 7.55 | 1.00 | 9.44 | 3.36 | 3.30 ± .53 | -- |
| 85-2897 | 41 | 2 | 32.301 | 7.90 | 0.94 | 9.40 | 2.73 | 3.27 ± .53 | -- |
| 85-2908 | 47 | 48 | 32.787 | 8.47 | 1.06 | 9.80 | 3.67 | 2.37 ± .55 | -- |
| 85-2909 | 47 | 3 | 32.787 | 8.47 | 1.06 | 9.80 | -- | 3.22 ± .53 | -- |
| 85-2910 | 47 | 1 | 32.787 | 8.47 | 1.06 | 9.80 | -- | 2.70 ± .53 | -- |
| 85-2911 | 48 | 28 | 32.773 | 7.42 | 1.00 | 8.18 | 10.5 | 3.17 ± .53 | 4.3 ± 2.5 |
| 85-2914 | 49 | 3 | 32.769 | 6.25 | 0.86 | 7.23 | 3.22 | 2.80 ± .52 | -- |
| 85-2916 | 51 | 26 | -- | 6.67 | 0.91 | 7.53 | 3.04 | 3.70 ± .55 | 4.3 ± 2.5 |
| 85-2920 | 53 | 1 | 32.767 | 9.07 | 1.00 | 10.05 | 12.62 | 3.15 ± .57 | 6.7 ± 2.5 |
| 85-2921 | 54 | 25 | 32.770 | 7.48 | 1.09 | 8.90 | 12.81 | 3.35 ± .55 | 4.6 ± 2.5 |
| 85-2924 | 55 | 4 | 32.778 | 7.92 | 1.10 | 8.86 | 7.25 | 3.68 ± .50 | -- |
| 85-2925 | 56 | 20 | 32.718 | 8.47 | 0.92 | 8.62 | 13.32 | 3.43 ± .57 | 3.4 ± 2.6 |
| 85-2928 | 57 | 1 | 32.664 | 7.81 | 0.93 | 8.88 | 14.28 | 2.71 ± .48 | < 2 |
| 85-2929 | 58 | 29 | -- | 8.04 | 0.92 | 8.85 | 2.99 | 2.76 ± .54 | 3.4 ± 2.6 |
| 85-2932 | 59 | 4 | 32.667 | 8.47 | 0.96 | 9.56 | 4.05 | 2.90 ± .53 | 2.5 ± 2.4 |
| 85-2933 | 60 | 29 | 32.696 | 8.04 | 0.98 | 9.44 | 2.53 | 2.94 ± .53 | -- |
| 85-2936 | 61 | 4 | 32.724 | 7.01 | 0.86 | 7.96 | 12.03 | 3.15 ± .53 | < 3 |
| 85-2937 | 62 | 30 | 32.756 | 6.94 | 0.92 | 8.01 | 14.74 | 3.15 ± .55 | -- |
| 85-2940 | 63 | 3 | 32.744 | 6.65 | 0.85 | 7.64 | 14.39 | 3.04 ± .50 | 2.5 ± 2.5 |

Table 3 (Cont'd.). Soluble Cs-137, H-3, SPM and nutrient results for selected stations sampled during Cruise 85-041.

| SAMPLE | STATION # | DEPTH (m) | SALINITY ‰ | SILICATE (μg-AT/ℓ) | PHOSPHATE (μg-AT/ℓ) | NITRATE (μg-AT/ℓ) | SPM (mg/ℓ) | Cs-137 (mBq/ℓ) | H-3 (Bq/ℓ) |
|---|---|---|---|---|---|---|---|---|---|
| 85-2941 | 64 | 2 | 32.731 | 6.36 | 0.94 | 7.34 | 26.37 | 3.24 ± .53 | -- |
| 85-2943 | 65 | 22 | 32.710 | 7.02 | 1.09 | 8.32 | 15.14 | 2.95 ± .60 | 4.5 ± 2.8 |
| 85-2946 | 66 | 3 | 32.742 | 8.24 | 0.96 | 9.30 | 3.58 | 3.63 ± .50 | -- |
| 85-2947 | 67 | 26 | 32.675 | 7.82 | 1.00 | 9.12 | 11.29 | 3.87 ± .53 | -- |
| 85-2950 | 68 | 1 | 32.673 | 8.39 | 1.02 | 9.92 | 2.37 | 2.45 ± .53 | -- |
| 85-2951 | 69 | 31 | 32.462 | 7.79 | 0.98 | 9.10 | 1.82 | 2.08 ± .55 | 4.3 ± 2.8 |
| 85-2954 | 70 | 3 | 32.517 | 7.14 | 0.84 | 8.42 | 1.87 | 3.24 ± .53 | 4.0 ± 2.4 |
| 85-2955 | 71 | 31 | 32.607 | 7.56 | 0.96 | 8.94 | 2.23 | 3.10 ± .48 | -- |
| 85-2958 | 72 | 4 | 32.621 | 8.12 | 0.94 | 9.21 | 12.84 | 2.97 ± .55 | <3 |
| 85-2959 | 73 | 31 | 32.753 | 7.74 | 0.98 | 9.15 | 3.02 | 3.22 ± .52 | -- |
| 85-2962 | 74 | 3 | 32.788 | 6.40 | 0.86 | 7.50 | -- | 3.63 ± .52 | 2.8 ± 2.8 |
| 85-2963 | 75 | 31 | 32.763 | 7.25 | 0.92 | 8.41 | -- | 3.27 ± .50 | -- |
| 85-2966 | 76 | 2 | 32.579 | 7.56 | 0.93 | 9.67 | -- | 2.90 ± .48 | 7.0 ± 2.9 |
| 85-2967 | 77 | 27 | 32.687 | 6.30 | 0.82 | 7.08 | -- | 2.88 ± .52 | -- |
| 85-2970 | 78 | 1 | 32.590 | 6.04 | 0.76 | 6.94 | -- | 3.38 ± .52 | 3.3 ± 2.9 |
| 85-2971 | 79 | 25 | 32.589 | 7.88 | 0.90 | 9.11 | -- | 2.75 ± .50 | 6.5 ± 2.9 |
| 85-2974 | 80 | 1 | 32.597 | 8.66 | 0.88 | 9.48 | -- | 2.80 ± .53 | 5.7 ± 2.8 |
| 85-2975 | 81 | 27 | 32.629 | 8.17 | 0.91 | 9.52 | -- | 2.71 ± .53 | 3.4 ± 2.9 |

Table 4. Average radionuclide values measured in the water column for all cruises.

| Cruise No. | Date | Radionuclide Concentrations | | Sr-90 mBq/ℓ | H-3 mBq/ℓ |
|---|---|---|---|---|---|
| | | Cs-137 (Particulate) mBq/ℓ | Cs-137 (Dissolved) mBq/ℓ | | |
| Pre-operational | | | | | |
| 79-007 | May 1-6, 1979 | - | 3.8* ± 0.7**, n=28 | 3 ± 1, n=13 | 2700 ± 3000 |
| 79.027 | Oct 24-28, 1979 | - | 2.6 ± 0.8 , n=24 | - | 1700 ± 2700 |
| 80-018 | Jun 9-14, 1980 | <0.8 | 4.2 ± 0.3 , n=43 | - | <2300 |
| 81-500 | Feb 23-26, 1981 | <1.5 | 4.4 ± 0.5 , n=20 | - | 2840 ± 1200 |
| 81-010 | Apr 14-21, 1981 | <1.2 | 3.5 ± 0.3 , n=33 | - | 2210 ± 580 |
| Post-operational | | | | | |
| 83-003 | Apr 12-18, 1983 | - | 3.3± 0.6 , n=30 | - | 2525 ± 910 |
| 84-025 | Jul 10-16, 1984 | <0.4 | 3.0± 0.5 , n=28 | | 2933 ± 611 |
| 85-041 | Dec 9-15, 1985 | <0.5 | 3.2±0.4 , n=18 | | 3885 ± 1343 |

* Mean radionuclide values calculated using a single mean from the anchor station data.

** Error reported is the statistical error for mean value.

peaks shown in Figure 7 are generally associated with intervals of maximum tidal flux. In general, current meter data indicate that the resuspension of bottom material due to changing current conditions and subsequent transport with the rising tide during periods of maximum current velocity may be a possible mechanism to explain peak SPM concentrations observed at the anchor stations.

Cs-137 activities for samples collected at the anchor station are shown in Figure 7 and in Table 3. The agreement between the average Cs-137 activity in the bottom water ($3.1 \pm 0.4$ mBq/$\ell$) and at the surface ($3.1 \pm 0.4$ mBq/$\ell$) and the low deviation from the mean for each illustrate the uniformity of the water mass in the Point Lepreau area during this time. The correlation between SPM and Cs-137 activities observed during previous cruises (Nelson *et al.* 1986) was not observed during cruise 85-041.

### 2.3.1.2 Gamma-Emitting Radionuclides

Neutron activation products of transition metals present in reactor support and encasement materials, such as Zn-65, Co-60, and Mn-54, are environmentally important radionuclides originating from nuclear weapons fallout and from reactor effluents. The stable element analogues are physiologically essential to marine organisms and concentration factors of $10^3$ to $10^5$ higher than seawater have been observed in various species (IAEA 1985b).

For analysis, the gamma-emitting radionuclides are concentrated from seawater by adsorption onto Chelex-100 (with the exception of I-131 and Cs-137). An average retention efficiently of 90% was determined using an NBS mixed gamma radionuclide standard. The detection limits in Appendix 3 are based on an assumed water volume of 50 litres with eluted samples counted for 1500 minutes, one month after the sample collection. As expected, all gamma-emitting radionuclides were below detection limits for all samples analyzed.

### 2.3.1.3 Plutonium in Seawater

The majority of plutonium entering marine systems originates from nuclear weapons testing. In addition accidental releases of Pu-238 to the environment have also occurred as a result of

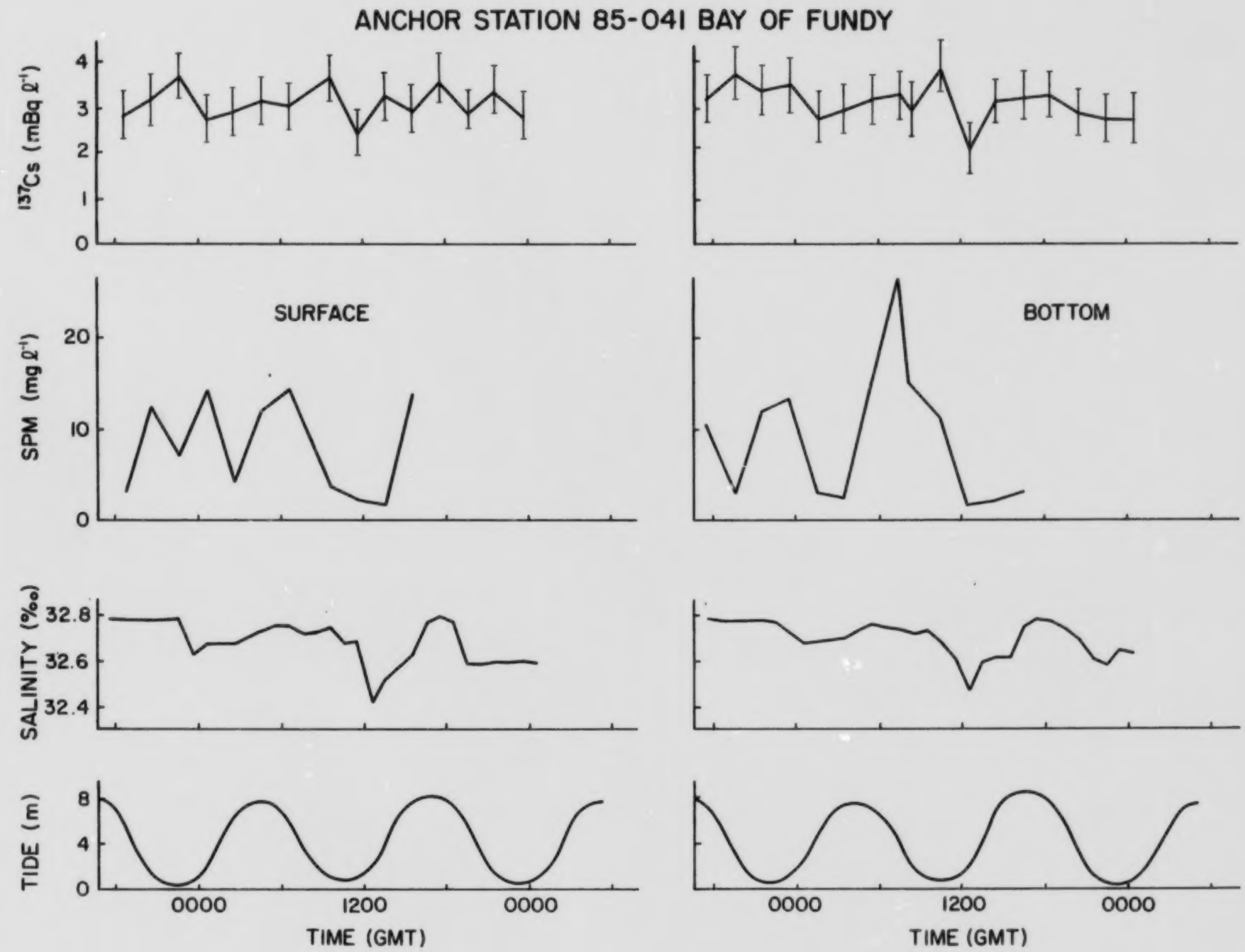


Figure 7. Cs-137, SPM, and salinity plotted as a function of time for water samples collected at the anchor station during cruise 85-041.

the re-entry burn-up of the nuclear powered SNAP-9A satellite in 1964. Plutonium-239 has also been released by accidents related to weapons uses of plutonium.

Isotopes of plutonium, namely Pu-238 ($t_{\frac{1}{2}}$=86.4y), Pu-239 ($t_{\frac{1}{2}}$=24,400y), Pu-240 ($t_{\frac{1}{2}}$=6000y) and Pu-241($t_{\frac{1}{2}}$=13y), because of their long half-lives and high chemical and radiotoxicity, are the important transuranic radionuclides in fallout. Plutonium is considered to be particle reactive and oceanic plutonium is distributed between approximately 30% dissolved and 70% particulate. Plutonium is depleted from surface waters rapidly compared with Cs-137 and Sr-90; the downward transport of Pu in fast settling zooplankton fecal pellets is an important component in the vertical transport of plutonium (NRCC, 1983).

Levels of soluble plutonium (Pu-239,240, Pu-238) in seawater were determined using a ferrous hydroxide precipitation technique on $100\ell$ water samples collected in the Bay of Fundy during cruise 85-041. The results are presented in Table 5. Soluble levels of Pu-239,240 and Pu-238 are comparable to those measured during cruise 81-010 (Ellis, *et al.* 1984) by D. Nelson (personal communication) and those measured during cruise 84-025 in this lab (Nelson *et al.* 1986).

A mean fallout activity ratio of 0.012 was estimated by Harley (1975) for Pu-239,240/Cs-137 from measurements conducted on air particulate samples collected during the early 1960s. Plutonium-239,240/Cs-137 inventory ratios in the Bay of Fundy sediments (average of 0.37) are greater than fallout ratios by an order of magnitude (Ellis *et al.* 1984), as a result of larger $k_D$ values for plutonium compared to Cs-137. The average Pu-239,240/Cs-137 ratio in Bay of Fundy water in 1984 is 0.004, much less than the fallout activity ratio. This low ratio is consistent with preferential adsorption of plutonium onto particles, followed by particle settling.

An average Pu-238/Pu-239,240 activity ratio of 0.077 was found for water samples collected in the Bay of Fundy during cruise 85-041. This ratio is much higher than the fallout activity pre-SNAP 9A ratio of 0.025 (Hardy *et al.* 1973), but is comparable to a level of 0.087 found in 1984 (Nelson *et al.* 1986) although large errors are associated with the determined ratios in both cases.

Table 5. Radionuclide results for plutonium in water samples collected during cruises 81-010, 84-025 and 85-041.

| Sample | | Depth | Particulate Pu-239,240 (mBq/ℓ) | Soluble Pu-239,240 (mBq/ℓ) | Total Pu-239,240 (mBq/ℓ) | Pu-238 (mBq/ℓ) | Ratio $\frac{\text{Pu-238}}{\text{Pu-239,240}}$ |
|---|---|---|---|---|---|---|---|
| No. | Station | | | | | | |
| 81-7962 | 23 | 66 | 0.013 ± 0.001 | 0.020 ± 0.001 | 0.033 ± 0.001 | - | - |
| 81-7982 | 30 | 125 | 0.004 ± 0.001 | 0.019 ± 0.001 | 0.023 ± 0.001 | - | - |
| 81-8063 | 62 | 37 | 0.052 ± 0.004 | 0.018 ± 0.006 | 0.070 ± 0.004 | - | - |
| 84-2107 | 3 | 1 | - | 0.009 ± 0.001 | - | 0.0012 ± 0.0005 | 0.14 ± 0.06 |
| 84-2141 | 19 | 3 | - | 0.011 ± 0.002 | - | 0.0010 ± 0.0005 | 0.10 ± 0.05 |
| 84-2153 | 23 | 1 | - | 0.010 ± 0.001 | - | 0.0005 ± 0.0002 | 0.05 ± 0.02 |
| 84-2302 | 44 | 1 | - | 0.009 ± 0.001 | - | 0.0003 ± 0.0002 | 0.04 ± 0.03 |
| 84-2315 | 50 | 4 | - | - | 0.010 ± 0.002 | 0.0014 ± 0.0008 | 0.14 ± 0.08 |
| 84-2364 | 74 | 1 | - | - | 0.013 ± 0.002 | 0.0006 ± 0.0004 | 0.05 ± 0.03 |
| 85-2815 | - | - | - | - | 0.020 ± 0.002 | 0.0013 ± 0.0007 | 0.065 ± 0.033 |
| 85-2918 | - | - | - | - | 0.021 ± 0.002 | 0.0006 ± 0.0003 | 0.029 ± 0.015 |

### 2.3.1.4 Tritium in Seawater

The major tritium inputs in the past have been associated with fallout from nuclear tests, in addition to the naturally occurring input from cosmogenic interactions in the upper atmosphere. Environmental releases of tritium from the Point Lepreau NGS will be substantially greater than those for any other radionuclide under normal operating conditions due to the use of heavy water ($D_2O$) as the moderator and coolant and because elevated levels of tritium associated with reactor releases are likely to be detectable in a range of environmental phases.

Water samples collected for tritium analysis in the Bay of Fundy were distilled under vacuum and counted for 500 or 1000 minutes in a liquid scintillation counter using methods outlined in previous reports (Ellis *et al.* 1984). The results for cruise 85-041 are given in Table 3. The range in tritium values for cruise 85-041 was <2.0 to 3.6 Bq/ℓ and the majority of seawater samples analyzed were below the detection limit. Tritium values for this cruise are comparable with those found during the pre-operational program (Table 4) indicating that no measurable increase in the overall seawater tritium activity occurred in the Bay of Fundy.

Water samples were collected for tritium analysis at the surface and bottom during December 1985 as part of a thermal plume study conducted at that time. A detailed discussion of these results is presented in Section 2.4.1.

### 2.3.2 Nutrients

The oceans, and particularly coastal waters, are inhomogenous mixtures with regard to chemical composition. In the majority of coastal waters, precipitation and freshwater mix into the surface layer and are advected away from the coast, being replaced by a subsurface input of relatively saline deep water. This process adds to the chemical inhomogeneity of coastal waters by replenishing chemicals lost from the surface layer by particulate settling and biological action.

Water samples for nutrients and salinity determinations were collected at selected water depths using 12-litre Niskin bottles. Nutrient samples were drawn directly from the Niskin bottles and stored frozen for subsequent analysis by standard auto-analysis techniques. Unfiltered water samples were also collected for salinity determinations. Selected results for nutrient analysis for cruise 85-041 are present in Table 3 and the values measured are within the ranges of values previously observed. The silicate-salinity relationship noted during previous cruises was not observed during cruise 85-041 probably because of the narrow range in salinities measured during this cruise.

## 2.4 Thermal Plume Study

The generation of electricity by all thermal processes is accompanied by the production of waste heat that must constantly be removed by means of a cooling water stream and ultimately dispersed into the surrounding environment. The Point Lepreau NSG has chosen the "once through" cooling system with offshore intake and discharge designed to take advantage of the rapid mixing present in the Bay of Fundy to disperse waste heat.

Changes in temperature affect both the physical and chemical properties of water and these changes result in a complex chain of events involving hydrodynamics, heat and mass transfer, biological and ecological factors (Miller *et al.* 1984). Ultimately the impact of thermal contamination on the environment will depend on the extent and duration of the thermal plume. The ensuing dispersal of heat through the receiving waters and into the atmosphere is controlled by current velocity, turbulance, temperature difference between air and water, the humidity of the air, and the speed and direction of the wind.

### 2.4.1 Thermal Plume Field Work

During 1985-86, three separate surveys of the Point Lepreau NGS cooling water outfall area were conducted. The first of these, (survey 85-900) spanned April 23-24, 1985. This survey was intended to examine the characteristics of the cooling water plume during spring when stratification of the receiving water by the spring freshet of the Saint John and other nearby rivers had previously been observed to alter plume dynamics in a profound manner (Nelson *et al.* 1985). The second survey, part of CSS Dawson cruise 85-041, was undertaken on December 12-13, 1985 and was intended to monitor conditions during early winter. The third, 86-900, was mounted in response to the existence of a small boiler tube leak and was carried out on February 25 and 27, 1986. More details of this leak and other studies conducted related to this event are presented in Chapter 6.

As in previous surveys, vertical profiles of temperature and salinity were obtained using a Guildline portable CTD system and water samples were collected at the surface and at depth for tritium analysis. The use of Loran-C for launch navigation permitted the estimation of surface current vectors, using the drift of the launch when wind was not a dominant factor. During the first two surveys, the NGS undertook controlled liquid waste pumpouts to provide measurable tritium levels in the outfall waters as an additional plume tracer. In addition, during cruise 85-041, CTD measurements and current observations were made from CSS Dawson which was anchored near the survey area.

The following sections briefly describe some of the observations made during these surveys.

### Survey 85-900 (April 1985)

Four separate sets of observations were obtained at different stages of the tide; high water, ½ tide falling, low water, and ½ tide rising. Salinity levels and gradients on the outfall (east) side of Point Lepreau were found to vary markedly between sets of observations. For example, during the ½ tide falling survey (survey #2) the water column on the east side of the point was uniformly quite fresh with an average salinity of approximately 28.2‰, (Table 6) but with very little vertical contrast, generally less than 0.2‰ from top to bottom. The low water conditions (survey #3) were marked by similar surface salinity values. However, the top to bottom contrast was approximately 3‰. A strong halocline existed at a depth of about 14 metres.

On the intake (west) side of Point Lepreau there was generally very little salinity stratification during these two surveys. Salinity values were generally greater, however, than those even at the bottom on the east side. This resulted in the discharged cooling water being significantly denser than the receiving water at the outfall depth even though the effluent was much warmer. Because of this, the effluent plume did not reach the surface, but was confined at mid-depth and under certain conditions was even held to the bottom. These points are best illustrated by a detailed examination of the results obtained from surveys 2 and 3.

## Survey #2

This survey was conducted over approximately 2 hours following ½ tide falling on April 23, 1985. The currents near the outfall site at this stage of the tide are dominated by northeasterly flow into Duck Cove, part of a back eddy induced on the east side of the point by the outgoing tide (Nelson *et al.* 1986). Unfortunately, strong onshore winds during this survey prevented the determination of meaningful surface currents from launch drift. The station positions are shown in Figure 8.

A small surface slick was observed near the outfall position. However, neither surface temperatures or tritium values were particularly elevated in the slick. Most of the stations occupied showed very little evidence of the presence of heated effluent, contrary to expectations. Elevated temperatures were observed near the bottom at several stations; eg. 14, 16 and 18. The cause of this phenomenon is illustrated in Figure 9. Salinities at the intake site (Station 17) are much greater than those at the outfall. At the intake depth, approximately 14 metres at this stage of the tide, the salinity was 31.5‰. The temperature of the discharge was 20.1°C (Table 7). This point is illustrated in the temperature - salinity diagram shown in Figure 9 along with the T-S curve for Station 14. Mixing will occur along the line shown. Because of the phenomenon of 'cabelling', which through non-linearities in the equation of state for seawater, results in mixed water being denser than either of the parent waters, the diluted effluent is denser than the receiving waters and sinks to the bottom. This is indicated by the slightly elevated temperatures near the bottom on the T-S curve for Station 14. Regretably, this effect was not anticipated during the survey and thus the spread of the plume along the bottom is not well resolved.

This aspect of the dynamics of the plume, which will result in increased exposure of benthic organisms to the effluent, requires further study to determine, among other things, how often these conditions might be expected to occur.

Table 6. Station locations, depths and times accompanied by discrete sampling observations for Survey 85 900.

| SAMPLE ID | STATION | DEPTH | SAMPLE DEPTH | H-3 | SALINITY | T °C | LATITUDE | LONGITUDE | GMT | DATE | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 85-02101 | 1 | 14 | 1 | -- | -- | 4.02 | 45°3.76'N | 66°27.02'W | 14:40 | 23-4-85 | Survey 1 |
| -02102 | | | 4 | -- | 30.21 | 4.46 | | | | | |
| -02103 | 2 | 16 | 1 | -- | 29.94 | 4.88 | 45°3.73'N | 66°27.04'W | 14:50 | " | |
| -02104 | | | 14 | -- | 30.47 | 2.98 | | | | | |
| -02105 | 3 | | 1 | -- | -- | -- | 45°3.88'N | 66°26.96'W | 14:59 | " | |
| -02106 | | | 16 | -- | 31.40 | 2.88 | | | | | |
| -02107 | 4 | 20 | 1 | -- | 30.03 | 4.34 | 45°3.76'N | 66°26.99'W | 15:16 | " | |
| -02108 | | | 15 | -- | 31.12 | 5.20 | | | | | |
| -- | 5 | -- | -- | -- | -- | -- | 45°3.82'N | 66°26.98'W | 15:36 | " | |
| -- | | | -- | -- | -- | -- | | | | | Survey 2 |
| -02109 | 6 | 15 | 1 | 2.2±2.6 | 28.31 | 4.12 | 45°3.80'N | 66°26.99'W | 20:41 | " | |
| -02110 | | | 14 | <2.1 | 28.39 | 3.89 | | | | | |
| -02111 | 7 | 14 | 1 | 2.2±2.6 | 28.23 | 3.97 | 45°3.79'N | 66°27.04'W | 20:46 | " | ←Start of pumpout |
| -02112 | | | 7 | <2.1 | 28.25 | 3.92 | | | | | |
| -02113 | 8 | 17 | 1 | " | 28.06 | 4.15 | 45°3.76'N | 66°27.01'W | 20:53 | " | |
| -02114 | | | 12 | " | 28.81 | 3.94 | | | | | |
| -02115 | 9 | 17 | 1 | " | 27.91 | 3.98 | 45°3.90'N | 66°26.98'W | 21:03 | " | |
| -02116 | | | 10 | " | 28.00 | 3.97 | | | | | |
| -02101 | 1 | 14 | 1 | -- | -- | 4.02 | 45°3.76'N | 66°27.02'W | 14:40 | 23-4-85 | Survey 1 |
| -02102 | | | 4 | -- | 30.21 | 4.46 | | | | | |
| -02103 | 2 | 16 | 1 | -- | 29.94 | 4.88 | 45°3.73'N | 66°27.04'W | 14:50 | " | |

Table 6 (Cont'd). Station locations, depths and times accompanied by discrete sampling observations for Survey 85 900

| SAMPLE ID | STATION | DEPTH | SAMPLE DEPTH | H-3 | SALINITY | T °C | LATITUDE | LONGITUDE | GMT | DATE | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 85-02104 | | | 14 | -- | 30.47 | 2.98 | | | | | |
| -02105 | 3 | | 1 | -- | -- | -- | 45°3.88'N | 66°26.96'W | 14:59 | " | |
| -02106 | | | 16 | -- | 31.40 | 2.88 | | | | | |
| -02107 | 4 | 20 | 1 | -- | 30.03 | 4.34 | 45°3.76'N | 66°26.99'W | 15:16 | " | |
| -02108 | | | 15 | -- | 31.12 | 5.20 | | | | | |
| -- | 5 | -- | -- | -- | -- | - | 45°3.82'N | 66°26.98'W | 15:36 | " | |
| -- | | | -- | -- | -- | -- | | | | | *Survey 2* |
| 02109 | 6 | 15 | 1 | 2.2±2.6 | 28.31 | 4.12 | 45°3.80'N | 66°26.99'W | 20:41 | " | |
| 02110 | | | 14 | <2.1 | 28.39 | 3.89 | | | | | |
| -02111 | 7 | 14 | 1 | 2.2±2.6 | 28.23 | 3.97 | 45°3.79'N | 66°27.04'W | 20.46 | " | ←Start of pumpout |
| -02112 | | | 7 | <2.1 | 28.25 | 3.92 | | | | | |
| -02113 | 8 | 17 | 1 | " | 28.06 | 4.15 | 45°3.76'N | 66°27.01'W | 20.53 | " | |
| -02114 | | | 12 | " | 28.81 | 3.94 | | | | | |
| 02115 | 9 | 17 | 1 | " | 27.91 | 3.98 | 45°3.90'N | 66°26.98'W | 21:03 | " | |
| -02116 | | | 10 | " | 28.00 | 3.97 | | | | | |
| -02117 | 10 | 17 | 1 | " | 28.21 | 4.80 | 45°3.82'N | 66°26.98'W | 21:09 | " | |
| -02118 | | | 13 | " | 28.08 | 4.10 | | | | | |
| -02119 | 11 | 17 | 1 | 2.8±2.6 | 27.98 | 3.99 | 45°3.85'N | 66°26.97'W | 21:17 | " | |
| 02120 | | | 11 | <2.1 | 28.12 | 3.91 | | | | | |
| -02121 | 12 | 11 | 1 | " | 28.30 | 3.87 | 45°3.97'N | 66°26.90'W | 21:24 | " | |
| -02122 | | | 7 | " | 28.29 | 3.87 | | | | | |

Table 6 (Cont'd). Station locations, depths and times accompanied by discrete sampling observations for Survey 85-900

| SAMPLE ID | STATION | DEPTH | SAMPLE DEPTH | H 3 | SALINITY | T°C | LATITUDE | LONGITUDE | GMT | DATE | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 85-02123 | 13 | 22 | 1 | 3.0±2.6 | 27.83 | 4.00 | 45°3.96'N | 66°26.88'W | 21:31 | " | |
| -02124 | | | 13 | <2.1 | 28.23 | 3.87 | | | | | |
| -02125 | 14 | 26 | 1 | | 28.03 | 3.95 | 45°3.81'N | 66°26.92'W | 21:38 | " | |
| -02126 | | | 21 | | 28.06 | 4.35 | | | | | |
| -02127 | 15 | 26 | 1 | | 27.73 | 3.97 | 45°3.79'N | 66°26.93'W | 21:45 | " | |
| | | | -- | -- | -- | -- | | | | | |
| -02128 | 16 | 26 | 1 | | 27.18 | 4.05 | 45°3.82'N | 66°27.01'W | 21:51 | " | |
| -02129 | | | 4 | | 28.06 | 4.43 | | | | | |
| -02130 | 17 | 20 | 1 | | 31.14 | 3.48 | 45°3.77'N | 66°27.94'W | 22:06 | " | intake |
| -02131 | | | 17 | | 31.54 | 3.10 | | | | | intake |
| -02132 | 18 | 22 | 1 | | 28.01 | 3.93 | 45°3.80'N | 66°26.94'W | 22:23 | " | |
| -02133 | | | 16 | | 28.21 | 5.42 | | | | | |
| -02134 | 19 | 20 | 1 | <1.5 | 28.44 | 3.61 | 45°3.75'N | 66°26.98'W | 12:14 | 24-4-85 | ←start of pumpout |
| -02135 | | | 19 | " | 31.69 | 2.50 | | | | | |
| -02136 | 20 | -- | 1 | " | 29.53 | 6.23 | 45°3.81'N | 66°26.95'W | 12:21 | " | |
| -02137 | | | 19 | " | 31.71 | 2.47 | | | | | |
| -02138 | 21 | 17 | 1 | " | 28.65 | 3.61 | 45°3.86'N | 66°26.94'W | 12:27 | " | |
| -02139 | | | 13 | 3.7±1.7 | 29.96 | 6.45 | | | | | |
| -02140 | 22 | -- | 1 | 2.5±1.7 | 28.34 | 3.64 | 45°3.88'N | 66°26.89'W | 12:34 | " | |
| -02141 | 23 | -- | 1 | <1.5 | 28.33 | 3.70 | 45°3.93'N | 66°26.86'W | 12:40 | " | |
| -02142 | 24 | 18 | 1 | <1.5 | 28.50 | 3.65 | 45°3.99'N | 66°26.83'W | 12:46 | " | |

Table 6 (Cont'd). Station locations, depths and times accompanied by discrete sampling observations for Survey 85 900

| SAMPLE ID | STATION | DEPTH | SAMPLE DEPTH | H 3 | SALINITY | T °C | LATITUDE | LONGITUDE | GMT | DATE | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 85 02143 | | | 16 | <1.5 | 31.69 | 2.49 | | | | | |
| 02144 | 25 | -- | 1 | 10.2±2.6 | 29.50 | 4.89 | 45°3.81'N | 66°27.00'W | 12:55 | " | |
| -02145 | | | 6 | 13.7±2.6 | 29.87 | 4.90 | | | | | |
| -02146 | 26 | -- | 1 | 8.8±2.6 | 28.79 | 4.19 | 45°3.85'N | 66°26.97'W | 13:00 | " | |
| -02147 | | | 12 | 17.7±2.7 | 30.17 | 6.64 | | | | | |
| -02148 | 27 | -- | 1 | <2.0 | 28.38 | 3.74 | 45°3.89'N | 66°26.90'W | 13:06 | " | |
| -02149 | | | 10 | 5.0±2.5 | 29.87 | 4.99 | | | | | |
| -02150 | 28 | -- | 1 | 2.9±2.5 | 28.39 | 3.71 | 45°3.95'N | 66°26.82'W | 13:12 | " | |
| -02151 | | | 19 | <2.0 | 31.72 | 2.48 | | | | | |
| -02152 | 29 | -- | 1 | 5.5±2.6 | 28.48 | 3.95 | 45°4.02'N | 66°26.83'W | 13:19 | " | |
| -02153 | | | 12 | 9.7±2.6 | 29.98 | 4.56 | | | | | |
| -02154 | 30 | 11 | 1 | <2.0 | 28.66 | 3.82 | 45°4.10'N | 66°26.83'W | 13:25 | " | |
| -02155 | | | 10 | 4.8±2.5 | 29.91 | 4.60 | | | | | |
| -02156 | 31 | -- | 1 | 6.4±2.6 | 28.81 | 3.85 | 45°3.79'N | 66°26.98'W | 13:33 | " | |
| 02157 | | | 10 | 18.0±2.7 | 30.52 | 6.14 | | | | | |
| -02158 | 32 | 24 | 1 | 3.4±2.5 | 28.28 | 3.88 | 45°3.73'N | 66°26.95'W | 13:39 | " | |
| -02159 | | | 22 | 2.6±2.5 | 31.66 | 2.54 | | | | | |
| 02160 | 33 | 18 | 1 | <2.1 | 31.25 | 3.27 | 45°3.77'N | 66°27.94'W | 13:54 | " | intake |
| -02161 | | | 17 | <2.1 | 31.93 | 2.39 | | | | | intake |
| -02162 | 34 | 24 | 1 | 2.3±2.6 | 28.68 | 3.66 | 45°3.71'N | 66°26.97'W | 14:07 | " | |
| -02163 | | | 20 | 2.3±2.6 | 31.53 | 2.68 | | | | | |

Table 6 (Cont'd). Station locations, depths and times accompanied by discrete sampling observations for Survey 85 900.

| SAMPLE ID | STATION | DEPTH | SAMPLE DEPTH | H 3 | SALINITY | T°C | LATITUDE | LONGITUDE | GMT | DATE | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 85-02164 | 35 | 18 | 1 | < 2.1 | 28.62 | 3.97 | 45°3.89'N | 66°26.93'W | 14.15 | " | |
| -02165 | | | 18 | 4.0 ± 2.6 | 31.57 | 2.72 | | | | | |
| -02166 | 36 | 20 | 1 | - | 29.74 | 3.68 | 45°3.84'N | 66°26.99'W | 18.05 | " | |
| 02167 | | | 18 | -- | 31.70 | 3.25 | | | | | |
| -02168 | 37 | | 1 | -- | 29.95 | 3.57 | 45°3.77'N | 66°26.99'W | 18:11 | " | |
| -02169 | | | 18 | -- | 31.86 | 2.50 | | | | | |
| -02170 | 38 | 18 | 1 | -- | 29.77 | 3.78 | 45°3.84'N | 66°27.01'W | 18:19 | " | ←start of pumpout |
| -02171 | | | 17 | -- | 31.75 | 3.96 | | | | | |
| -02172 | 39 | -- | 1 | -- | 29.83 | 3.72 | 45°3.77'N | 66°26.99'W | 18:24 | " | |
| 02173 | | | 18 | -- | 31.85 | 2.46 | | | | | |
| -02174 | 40 | | 1 | -- | 29.91 | 3.59 | 45°3.87'N | 66°27.0 1'W | 18.33 | " | |
| -02175 | | | 18 | -- | 31.85 | 2.47 | | | | | |
| -02176 | 41 | -- | 1 | -- | 29.87 | 3.62 | 45°3.80'N | 66°26.97'W | 18:38 | " | |
| -02177 | | | 20 | -- | 31.88 | 2.42 | | | | | |
| -02178 | 42 | -- | 1 | -- | 30.33 | 3.51 | 45°3.69'N | 66°27.02'W | 18:44 | " | |
| -02179 | | | 21 | -- | 31.79 | 2.47 | | | | | |
| -02180 | 43 | -- | 1 | -- | 29.70 | 3.80 | 45°3.84'N | 66°26.99W | 18.52 | " | |
| -02181 | | | 16 | -- | 31.49 | 3.88 | | | | | |
| -02182 | 44 | -- | 1 | -- | 29.71 | 3.85 | 45°3.78'N | 66°27.00W | 18.59 | " | |
| -02183 | | | 19 | -- | 31.93 | 2.36 | | | | | |
| -02184 | 45 | 24 | 1 | -- | 29.89 | 4.81 | 45°3.76'N | 66°27.93W | 19.12 | " | intake |

Table 6 (Cont'd) Station locations, depths and times accompanied by discrete sampling observations for Survey 85 900

| SAMPLE ID | STATION | DEPTH | SAMPLE DEPTH | H 3 | SALINITY | T°C | LATITUDE | LONGITUDE | GMT | DATE | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 85-02185 | | | 18 | -- | 31 11 | 3 69 | | | | | intake |
| 02186 | 46 | -- | 1 | -- | 29 78 | 3 85 | 45°3 81'N | 66°26 98W | 19 28 | " | |
| 02187 | | | 18 | -- | 31 91 | 2 37 | | | | | |

## Survey #3

This survey was accomplished over approximately 2 hours following low water on April 24, 1985. The currents near the outfall during this period are a residual flow of the back eddy set up by the outflowing tide and are weakly tending northeast into Duck Cove. Figure 10 gives the station pattern. A surface slick was observed near the outfall, but away from it, surface temperatures were not elevated. Figures 11 and 12 show the vertical sections of temperature and salinity along the line indicated on Figure 10.

The core of the plume is seen to be confined to a depth of about 8 metres, the approximate depth of the outfall structure. The temperature salinity diagram shown in Figure 13 indicated that this is the depth at which the diluted effluent should lie given the density of the resulting mixture.

Effluent dilutions calculated from the tritium observations agree very well with those calculated from the temperature distributions, once sufficient time has elapsed for the tritium-labeled effluent to spread through the survey area.

## Survey 85-041 (December 1985)

Four sets of observations were again obtained at different stages of the tide. At this time (early winter) very little salinity contrast was observed either from top to bottom in the water column or from one side of Point Lepreau to the other. Some slightly fresher water (approximately 0.2‰ fresher) did enter the survey area briefly with the rising tide on December 13, but this had little effect on the plume dynamics. As a results of these conditions, the thermal plume was a surface phenomenon, elevated temperatures being observed only near the surface, once a short distance from the outfall (Table 8).

The details of the liquid waste pumpouts for this survey are given in Table 9. Figure 14 illustrates the station locations and surface temperature contours for the ½ tide falling survey, while Figure 15 shows the observed surface currents and calculated dilution contours. For this and other stages of the tide not shown here, the dilution contours and and surface currents compare well with previous observations made under nonstratified conditions (Nelson *et al.* 1986).

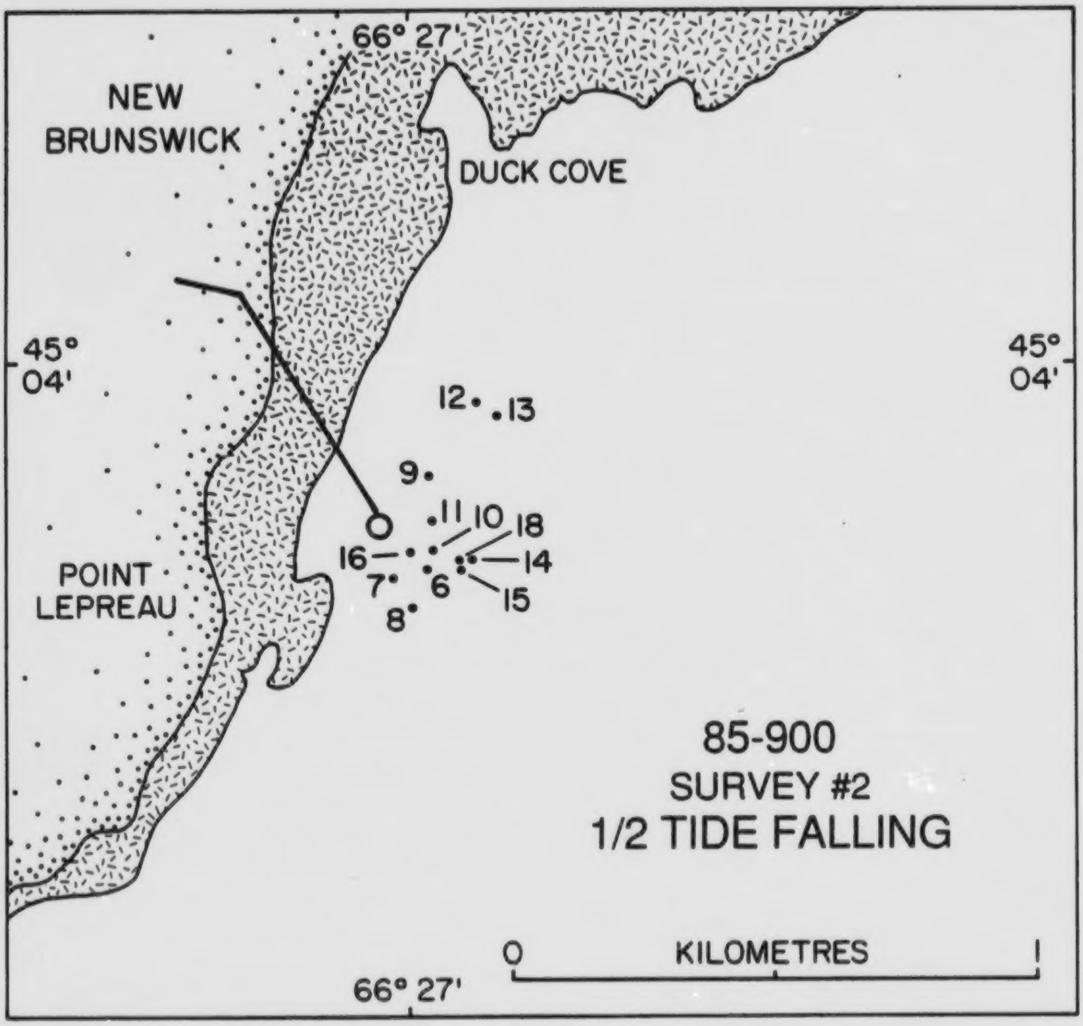

66° 27'
NEW BRUNSWICK
DUCK COVE
45° 04'
45° 04'
12
13
9
11
10
18
16
14
7
6
15
8
POINT LEPREAU
85-900
SURVEY #2
1/2 TIDE FALLING
0
KILOMETRES
1
66° 27'

Figure 8. Station locations for survey #2, 85-900.

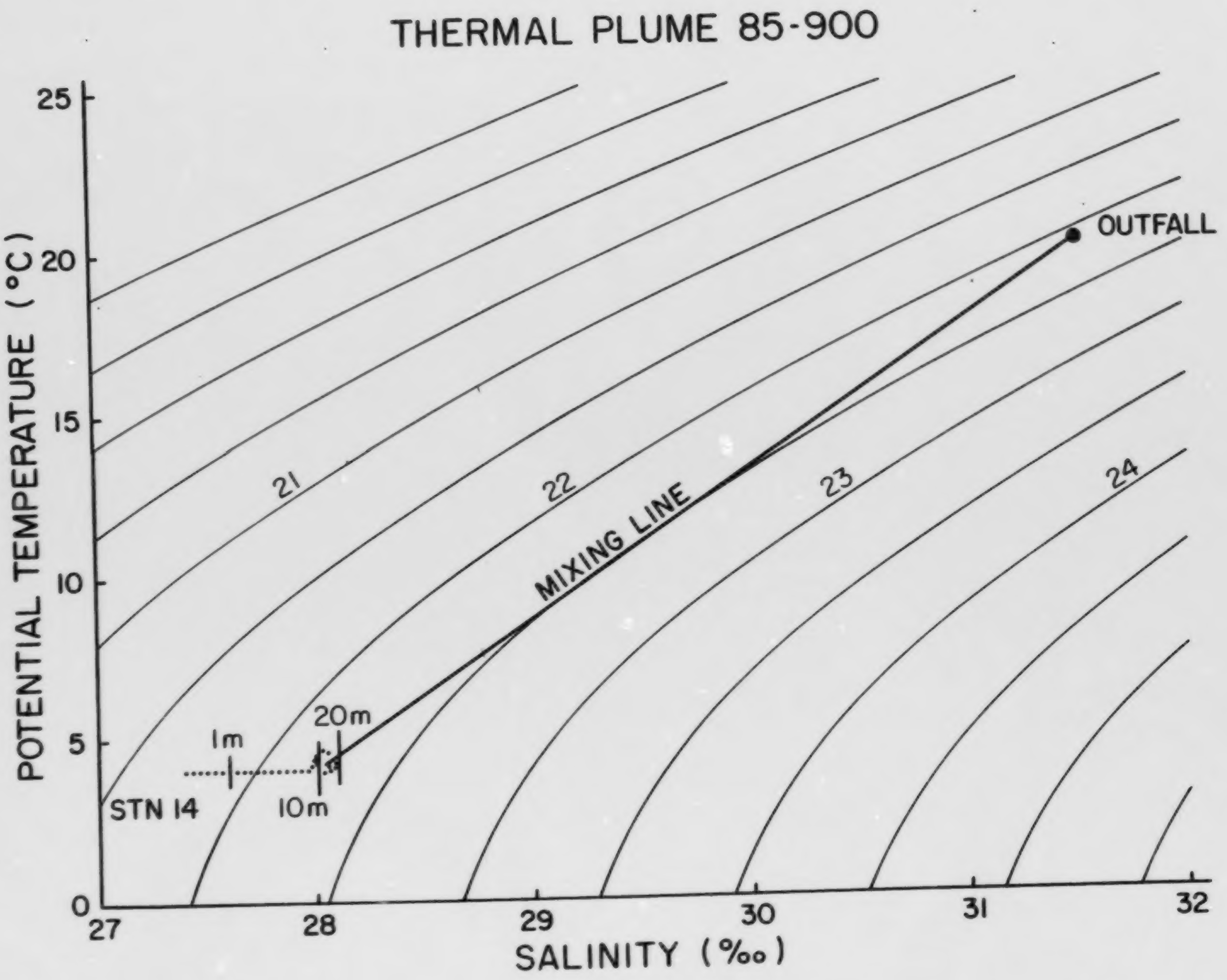


Figure 9. Temperature salinity diagram with lines for equal t (density) showing how diluted effluent is denser than the receiving waters near the bottom for survey #2, 85-900.

Table 7. Details of liquid waste pumpouts for survey 85-900 (J.J. Paciga, personal communication).

| Start of Pumpout GMT | | Outfall H-3 (Bq/ℓ) | Outfall Temperature (°C) |
|---|---|---|---|
| 85.04.23 | 15.57 | 140 | 21.5 |
| 85.04.23 | 20.46 | 70 | 20.1 |
| 85.04.24 | 12.15 | 85 | 19.7 |
| 85.04.24 | 18.20 | 70 | 20.6 |

Figure 16 shows the currents observed at CSS Dawson at a depth of 9 m during December 12-13, 1987. The position of CSS Dawson is shown in Figure 14. These and other observations taken during other surveys illustrate several interesting points about the currents in the outfall area. There is generally very little vertical shear in the currents, velocities being essentially uniform from top to bottom. The effect of the complicated eddy structure near the point is also shown with peak currents setting toward the southwest at high water.

### Survey 86-900 (February 1986)

As mentioned previously, this survey was undertaken in response to a small boiler tube leak which was detected in late December 1985. Conditions during the survey were rather less than ideal with brisk winds and low air temperatures. Two sets of observations were obtained, one spanning the 4 hours following high water on February 25 and another about 1 hour following low water on February 27. Station locations are shown on Figures 17 and 18.

Seawater tritium levels observed during the high water survey were slightly above background level (assumed to be 2.5 Bq/ℓ) in all cases (Table 10). Station 13 on the intake side of Point Lepreau also exhibited slightly elevated levels. This is in contrast to previous surveys during which measurements conducted away from the direct influence of the plume yielded tritium levels equivalent to or below the assumed background level.

Water temperatures were not particularly elevated during the high water survey, but this is not unexpected considering the vigorous mixing occuring near the outfall at this stage of the tide. In addition, temperature and tritium exhibited no significant correlation. (Figure 19). There are two possible explanations for this. The nature of the leak might have been such that the cooling water tritium concentrations varied markedly over time, or perhaps the waters near Point Lepreau may have remained in the area long enough to be significantly affected by surface cooling. A surface heat flux of 250 Watts/m$^2$, not unreasonable for this time of year, acting over two tidal cycles, would lower the temperature of a column of water 10 m deep by over 0.5°C. The elevated tritium levels at the intake station and in the bottom samples perhaps lend some support to the surface cooling hypothesis.

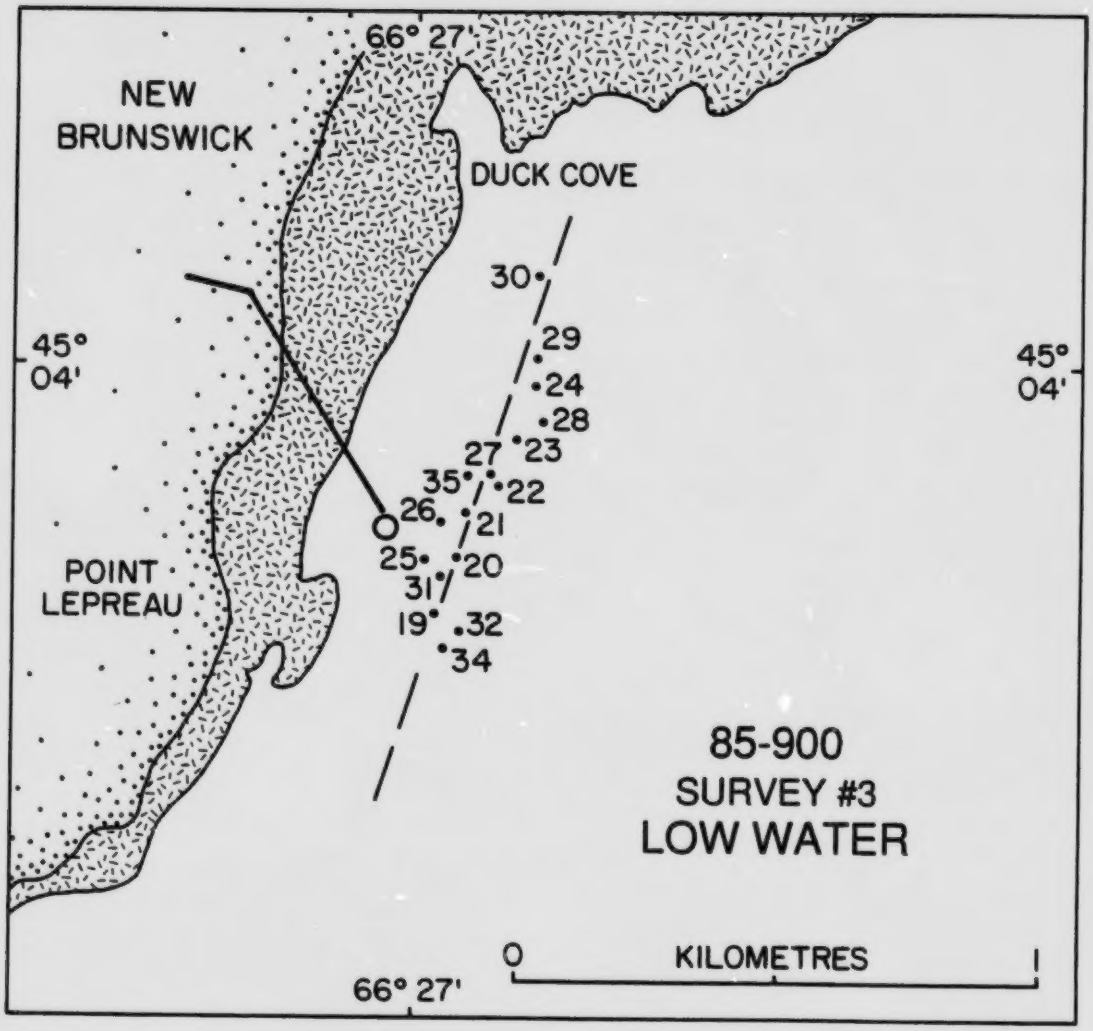

66° 27'
NEW BRUNSWICK
DUCK COVE
45° 04'
45° 04'
POINT LEPREAU
30
29
24
28
27
23
35
22
26
21
25
20
31
19
32
34
85-900
SURVEY #3
LOW WATER
0
KILOMETRES
1
66° 27'

Figure 10. Station locations for survey #3, 85-900. The dashed line indicates the position of the vertical section shown in Figures 11 and 12.

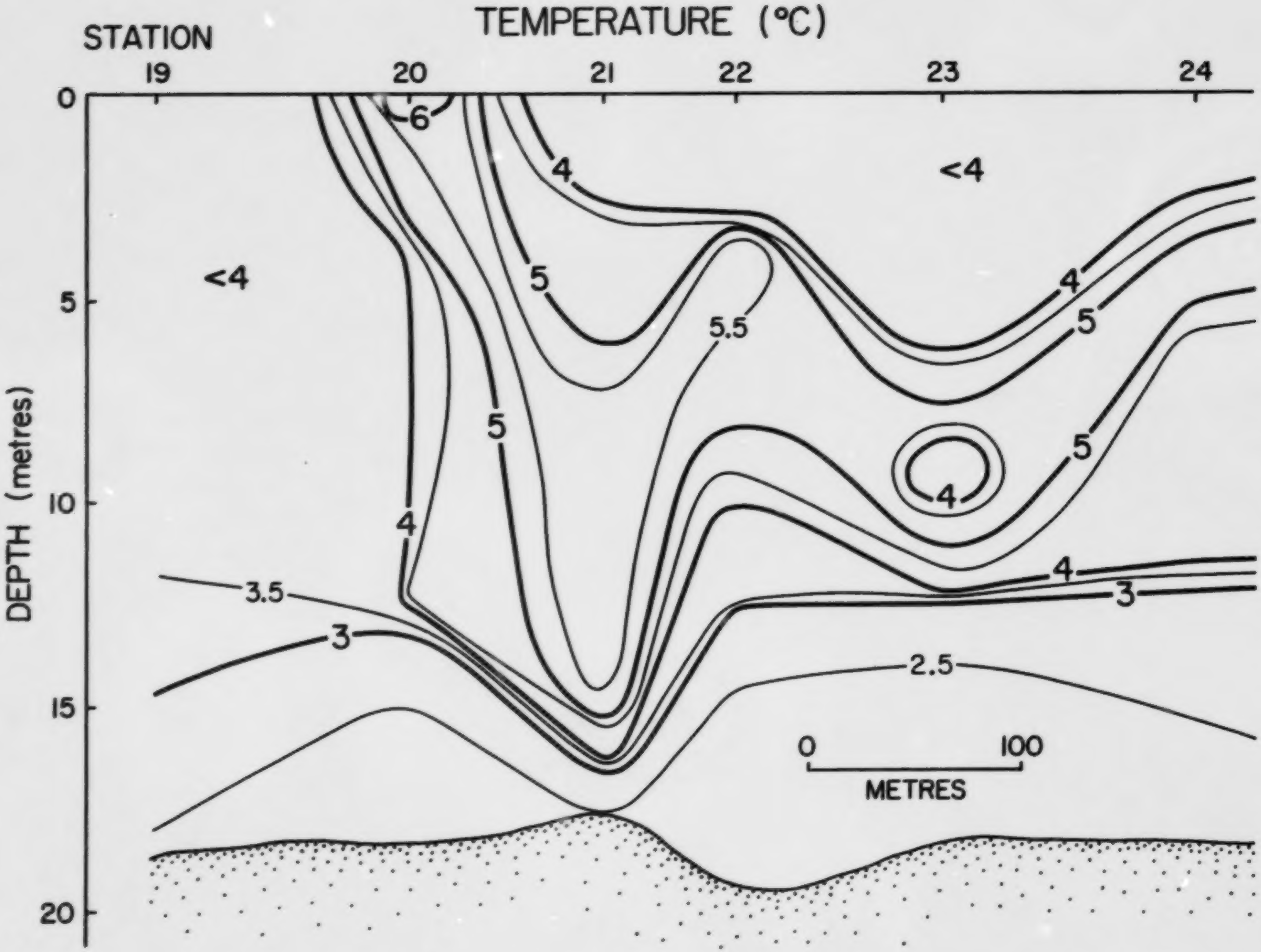


Figure 11. Vertical temperature section as shown in Figure 10. Contour interval is 0.5°C.

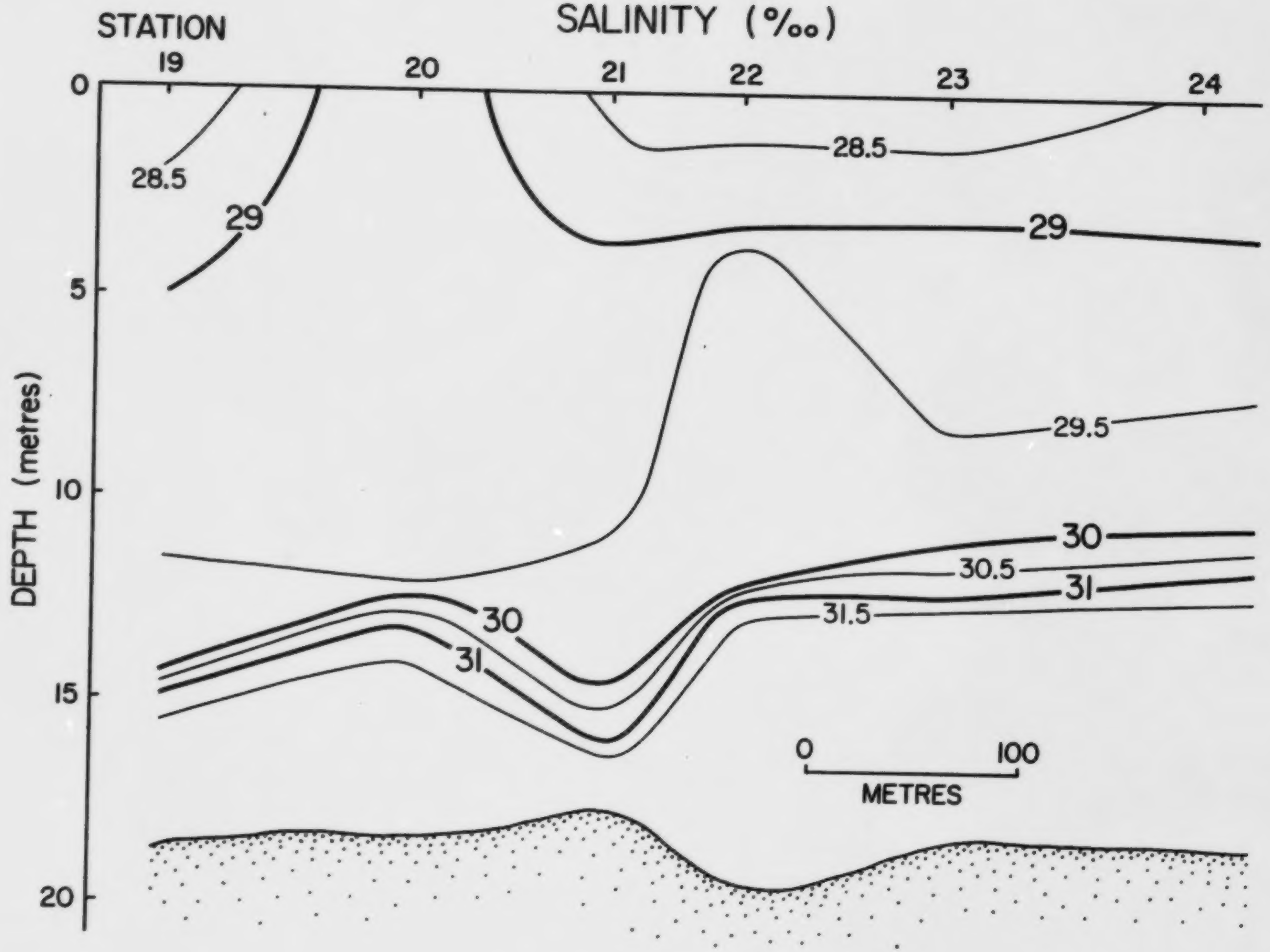


Figure 12. Vertical salinity section as shown in Figure 10. Contour interval is 0.5 parts per thousand.

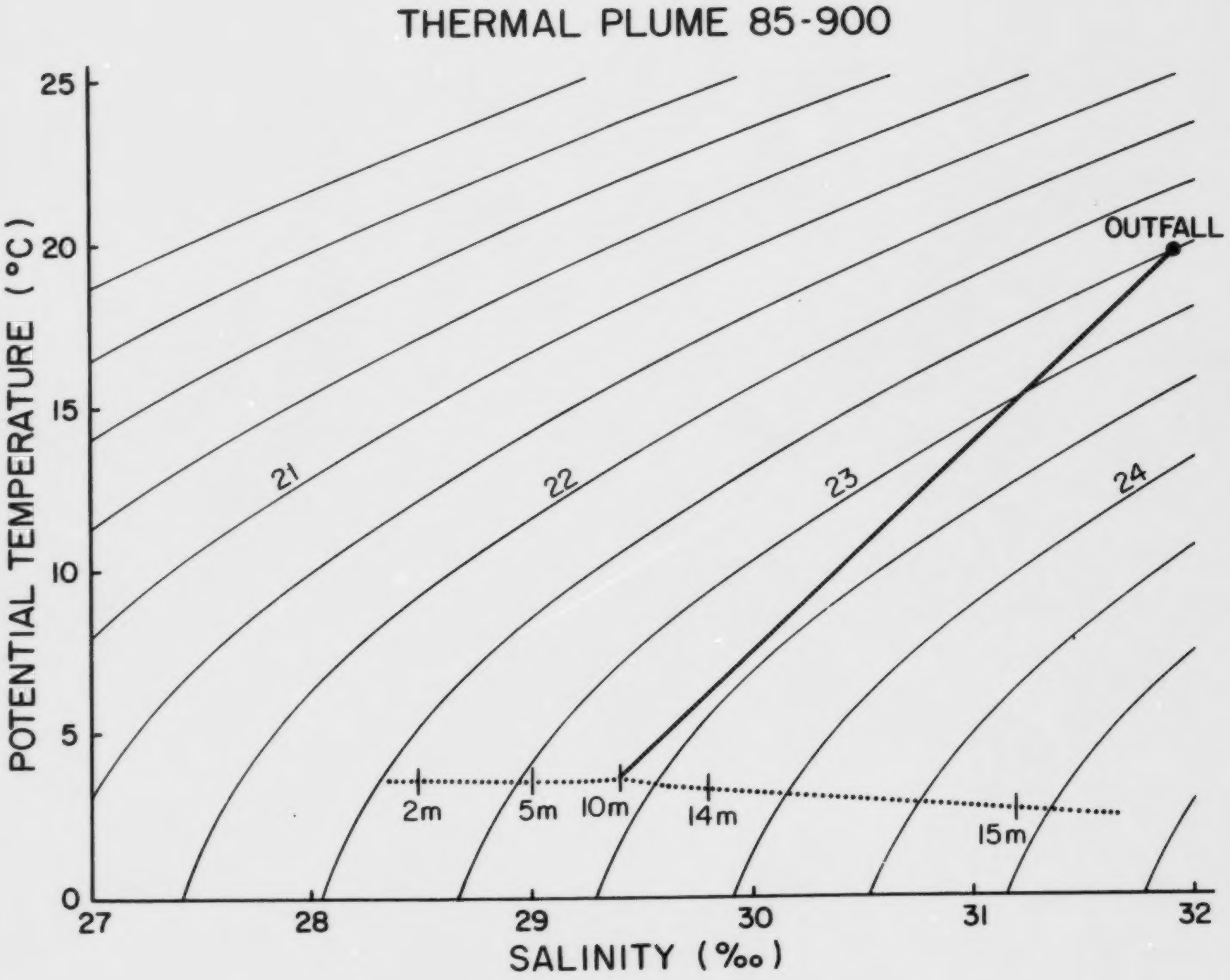


Figure 13. Temperature salinity diagram for survey #3, Cruise 85-900.

Table 8. Station locations, depths, and times along with discrete sample observations for Survey 85-041.

| Sample ID | Station | Depth | Sample Depth (M) | H-3 Bq$\ell^{-1}$ | Salinity | T°C | Latitude | Longitude | GMT | Date |
|---|---|---|---|---|---|---|---|---|---|---|
| 13601 | 1 | 22 | 16 | $L_c$(2.2) | 32.77 | 7.00 | 45°03.76 | 66°26.89 | 21:56 | 12-12-85 |
| 13603 | 2 | 9 | 1 | " | 32.72 | 8.30 | 45°03.92 | 66°26.93 | 22:11 | 12-12-85 |
| 13604 | | | 8 | " | 32.77 | 7.85 | | | | 12-12-85 |
| 13605 | 3 | 26 | 1 | " | 32.76 | 6.07 | 45°03.81 | 66°26.82 | 22:23 | 12-12-85 |
| 13606 | | | 21 | " | 32.77 | 7.01 | | | | 12-12-85 |
| 13607 | 4 | 18 | 1 | 11.4±2.7 | 32.73 | 7.81 | 45°03.97 | 66°26.74 | 22:38 | 12-12-85 |
| 13608 | | | 16 | $L_c$(2.2) | 32.76 | 6.07 | | | | 12-12-85 |
| 13609 | 5 | 5 | 1 | " | 32.74 | 7.90 | 45°04.06 | 66°26.85 | 22:49 | 12-12-85 |
| 13610 | | | 4 | " | 32.70 | 6.28 | | | | 12-12-85 |
| 13611 | 6 | 27 | 1 | 2.6±2.6 | 32.76 | 6.06 | 45°03.87 | 66°26.63 | 23:00 | 12-12-85 |
| 13612 | | | 22 | $L_c$(2.2) | 32.75 | 6.72 | | | | 12-12-85 |
| 13613 | 7 | 15 | 1 | 22.9±2.8 | 32.73 | 8.22 | 45°03.82 | 66°26.94 | 23:20 | 12-12-85 |
| 13614 | | | 13 | 13.8±2.7 | 32.68 | 7.96 | | | | 12-12-85 |
| 13615 | 8 | 18 | 1 | 9.0±2.7 | 32.72 | 7.84 | 45°03.83 | 66°26.94 | 23:32 | 12-12-85 |
| 13616 | | | 14 | 11.7±2.7 | 32.72 | 10.75 | | | | 12-12-85 |
| 13617 | 9 | 9 | 1 | 8.6±2.7 | 32.69 | 7.25 | 45°03.95 | 66°26.91 | 23:48 | 12-12-85 |
| 13618 | | | 8 | 11.6±2.7 | 32.75 | 7.18 | | | | 12-12-85 |
| 13619 | 10 | 33 | 1 | <2.5 | 32.60 | 6.96 | 45°03.75 | 66°26.70 | 00:03 | 13-12-85 |
| 13620 | | | 28 | <3.0 | 32.71 | 6.26 | | | | 13-12-85 |
| 13621 | 11 | 16 | 1 | 4.8±2.7 | 32.66 | 8.34 | 45°03.82 | 66°26.91 | 00:22 | 13-12-85 |
| 13622 | | | 14 | 2.5±2.6 | 32.62 | 6.94 | | | | 13-12-85 |
| 13623 | 12 | 26 | 1 | 2.9±2.6 | 32.47 | 6.92 | 45°03.82 | 66°26.79 | 13:06 | 13-12-85 |

Table 8 (Cont'd): Station locations, depths, and times along with discrete sample observations for Survey 85-041.

| Sample ID | Station | Depth | Sample Depth (M) | H-3 $Bq\ell^{-1}$ | Salinity | T°C | Latitude | Longitude | GMT | Date |
|---|---|---|---|---|---|---|---|---|---|---|
| 13624 | | | 24 | 3.9±2.7 | 32.55 | 6.98 | | | | 13-12-85 |
| 13625 | 13 | 30 | 1 | 3.2±2.7 | 32.59 | 7.75 | 45°03.84 | 66°26.87 | 13:24 | 13-12-85 |
| 13626 | | | 25 | 6.1±2.7 | 32.69 | 6.90 | | | | 13-12-85 |
| 13627 | 14 | 30 | 1 | 4.6±2.7 | 32.64 | 8.78 | 45°03.75 | 66°26.92 | 13:35 | 13-12-85 |
| 13628 | | | 26 | <3.969 | 32.68 | 7.14 | | | | 13-12-85 |
| 13629 | 15 | 38 | 1 | 2.2±2.7 | 32.56 | 7.79 | 45°03.65 | 66°26.89 | 13>50 | 13-12-85 |
| | | | 33 | | | 6.94 | | | | 13-12-85 |
| 13630 | 16 | 20 | 33 | 8.9±2.8 | 32.65 | 8.15 | 45°03.61 | 66°27.13 | 14:16 | 13-12-85 |
| 13631 | | | 18 | 2.4±2.7 | 32.61 | 7.43 | | | | 13-12-85 |
| 13632 | 17 | 37 | 1 | 5.2±2.7 | 32.58 | 7.48 | 45°03.46 | 66°27.06 | 14:24 | 13-12-85 |
| 13633 | | | 34 | 2.9±2.7 | 32.69 | 6.80 | | | | 13-12-85 |
| 13634 | 18 | 29 | 1 | 8.8±2.8 | 32.58 | 7.70 | 45°03.58 | 66°27.01 | 14:35 | 13-12-85 |
| 13635 | | | 27 | 3.9±2.8 | 32.62 | 6.91 | | | | 13-12-85 |
| 13636 | 19 | 26 | 1 | 20.2±3.0 | 32.48 | 7.82 | 45°03.77 | 66°26.94 | 14:44 | 13-12-85 |
| 13637 | | | 23 | 20.2±3.0 | 32.57 | 6.86 | | | | 13-12-85 |
| 13638 | 20 | 20 | 1 | 3.0±2.8 | 32.46 | 6.75 | 45°03.92 | 66°26.92 | 14:54 | 13-12-85 |
| 13639 | | | 17 | <4.395 | 32.59 | 6.91 | | | | 13-12-85 |
| 13640 | 21 | 22 | 1 | <3.507 | 32.53 | 7.60 | 45°03.84 | 66°26.90 | 15:02 | 13-12-85 |
| 13641 | | | 20 | 11.92.9 | 32.56 | 6.85 | | | | 13-12-85 |
| 13642 | 22 | 27 | 1 | -- | 32.69 | 6.84 | 45°03.90 | 66°26.85 | 16:21 | 13-12-85 |
| 13643 | | | 24 | <2.0 | 32.72 | 6.86 | | | | 13-12-85 |

Table 8 (Cont'd): Station locations, depths, and times along with discrete sample observations for Survey 85-041.

| Sample ID | Station | Depth | Sample Depth (M) | H-3 Bq$\ell^{-1}$ | Salinity | T°C | Latitude | Longitude | GMT | Date |
|---|---|---|---|---|---|---|---|---|---|---|
| 13644 | 23 | 27 | 1 | <2.0 | 32.72 | 8.18 | 45°03.84 | 66°26.88 | 16:28 | 13-12-85 |
| 13645 | | | 19 | <3.4 | 32.72 | 6.87 | | | | 13-12-85 |
| 13646 | 24 | 29 | 1 | $L_c$(1.5) | 32.73 | 7.32 | 45°03.69 | 66°26.92 | 16:35 | 13-12-85 |
| 13647 | | | 28 | 2.1 ± 2.3 | 32.71 | 6.89 | | | | 13-12-85 |
| 13648 | 25 | 31 | 1 | <2.8 | 32.65 | 7.63 | 45°03.60 | 66°27.09 | 16:42 | 13-12-85 |
| 13649 | | | 24 | 9.1 ± 2.3 | 32.70 | 6.83 | | | | 13-12-85 |
| 13650 | 26 | 29 | 1 | $L_c$(1.5) | 32.62 | 6.88 | 45°03.75 | 66°27.03 | 16:53 | 13-12-85 |
| 13651 | | | 6 | $L_c$ (1.5) | 32.69 | 6.88 | | | | 13-12-85 |
| 13652 | 27 | 15 | 1 | 3.2 ± 2.7 | 32.64 | 6.83 | 45°03.85 | 66°27.02 | 17:00 | 13-12-85 |
| 13653 | | | 13 | $L_c$(2.2) | 32.71 | 6.86 | | | | 13-12-85 |
| 13654 | 28 | 13 | 1 | <3.4 | 32.74 | 7.67 | 45°03.74 | 66°27.03 | 17:06 | 13-12-85 |
| 13655 | | | 7 | 12.7 ± 2.8 | 32.72 | 7.53 | | | | 13-12-85 |
| 13656 | 29 | 37 | 1 | 9.5 ± 2.7 | 32.79 | 6.94 | 45°03.48 | 66°27.05 | 17:12 | 13-12-85 |
| 13657 | | | 33 | $L_c$(2.2) | 32.76 | 6.86 | | | | 13-12-85 |
| 13658 | 30 | 17 | 1 | $L_c$(1.5) | 32.64 | 6.75 | 45°03.78 | 66°27.78 | 17:25 | 13-12-85 |
| 13659 | | | 16 | <2.4 | 32.72 | 6.21 | | | | 13-12-85 |
| 13660 | 31 | 18 | 1 | 14.9 ± 2.8 | 32.75 | 7.69 | 45°03.79 | 66°26.98 | 17:46 | 13-12-85 |
| 13661 | | | 17 | 8.1 ± 2.7 | 32.66 | 7.46 | | | | 13-12-85 |
| 13662 | 32 | 18 | 1 | $L_c$(2.2) | 32.68 | 8.15 | 45°03.85 | 66°26.97 | 19:26 | 13-12-85 |
| 13663 | | | 16 | $L_c$(2.2) | 32.73 | 6.90 | | | | 13-12-85 |
| 13664 | 33 | 11 | 1 | 2.4 ± 3.7 | 32.69 | 7.96 | 45°03.97 | 66°26.90 | 19:34 | 13-12-85 |

Table 8 (Cont'd): Station locations, depths, and times along with discrete sample observations for Survey 85-041.

| Sample ID | Station | Depth | Sample Depth (M) | H-3 $Bq\ell^{-1}$ | Salinity | T°C | Latitude | Longitude | GMT | Date |
|---|---|---|---|---|---|---|---|---|---|---|
| 13665 | | | 9 | $L_c(2.2)$ | 32.72 | 7.01 | | | | 13-12-85 |
| 13666 | 34 | 7 | 1 | <3.4±0.9 | 32.77 | 7.51 | 45°04.97 | 66°26.84 | 19:40 | 13-12-85 |
| 13667 | 34 | 8 | 7 | 2.8±2.8 | 32.68 | 7.02 | | | | 13-12-85 |
| 13668 | 35 | 22 | 1 | <4.0 | 32.64 | 6.87 | 45°04.07 | 66°26.67 | 19:45 | 13-12-85 |
| | | | 19 | -- | 32.72 | | | | | 13-12-85 |
| 13669 | 36 | 24 | 1 | -- | 32.69 | 6.83 | 45°03.96 | 66°26.64 | 19:53 | 13-12-85 |
| 13670 | | | 20 | <4.117 | 32.70 | 6.87 | 45°03.94 | | | 13-12-85 |
| 13671 | 37 | 26 | 1 | 16.3±2.9 | 32.64 | 7.55 | | 66°26.80 | 20:01 | 13-12-85 |
| 13672 | | | 21 | <3.1 | 32.67 | 6.84 | | | | 13-12-85 |
| 13673 | 38 | | 1 | 2.5±2.8 | 32.69 | 6.81 | 45°03.79 | 66°26.76 | 20:08 | 13-12-85 |
| 13674 | | 27 | 23 | $(L_c)2.2$ | 32.71 | 6.83 | | | | 13-12-85 |

Table 9. Details of liquid waste pumpouts for survey 85-041 (J.J. Paciga personal communication).

| Pumpout No. | 4137 | 4140 | 4142 | 4143 |
|---|---|---|---|---|
| Start Date | 85-12-12 | 85-12-13 | 85-12-13 | 85-12-13 |
| Start Time (GMT) | 21:50 | 13:28 | 16:21 | 19:32 |
| Stop Time (Calculated) | 23:08 | 14:51 | 17:38 | 20:56 |
| Volume Discharged (ℓ) | 4.24E4 | 3.96E4 | 3.68E4 | 4.05E4 |
| Discharge Rate (L/S) | 8 | 8 | 8 | 8 |
| H-3 Activity Discharged (Bq) | 2.54E10 | 2.99E10 | 3.50E10 | 6.97E10 |
| Average Inlet Temp (°C) | 6 | 6 | 6 | 6 |
| Average Condenser Outlet Temp (°C) | 21.5 | 21.5 | 21.5 | 21.5 |
| Condenser Cooling Flow (L/S) | 2.5E4 | 2.5E4 | 2.5E4 | 2.5E4 |
| Expected Activity at Seawater Discharge Point (Bq/ℓ) | 190 | 240 | 300 | 625 |
| Tidal Condition | low water | 1/2 tide rising | high water | 1/2 tide falling |

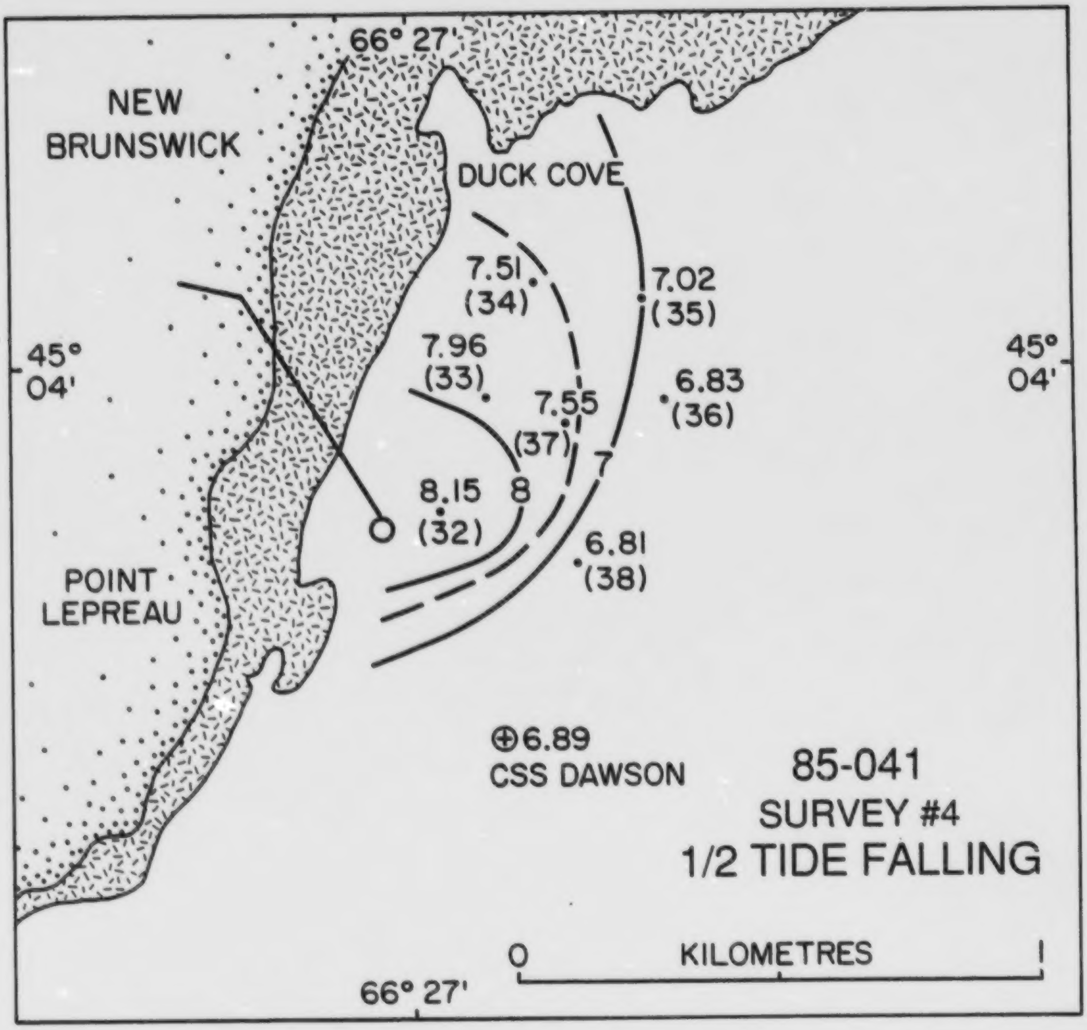

66° 27'
NEW BRUNSWICK
DUCK COVE
7.51 (34)
7.02 (35)
7.96 (33)
45° 04'
45° 04'
6.83 (36)
7.55 (37)
7
8
8.15 (32)
6.81 (38)
POINT LEPREAU
⊕6.89 CSS DAWSON
85-041
SURVEY #4
1/2 TIDE FALLING
0 KILOMETRES 1
66° 27'

**Figure 14.** Station locations and surface temperature contours for the ½tide falling survey, 85-041.

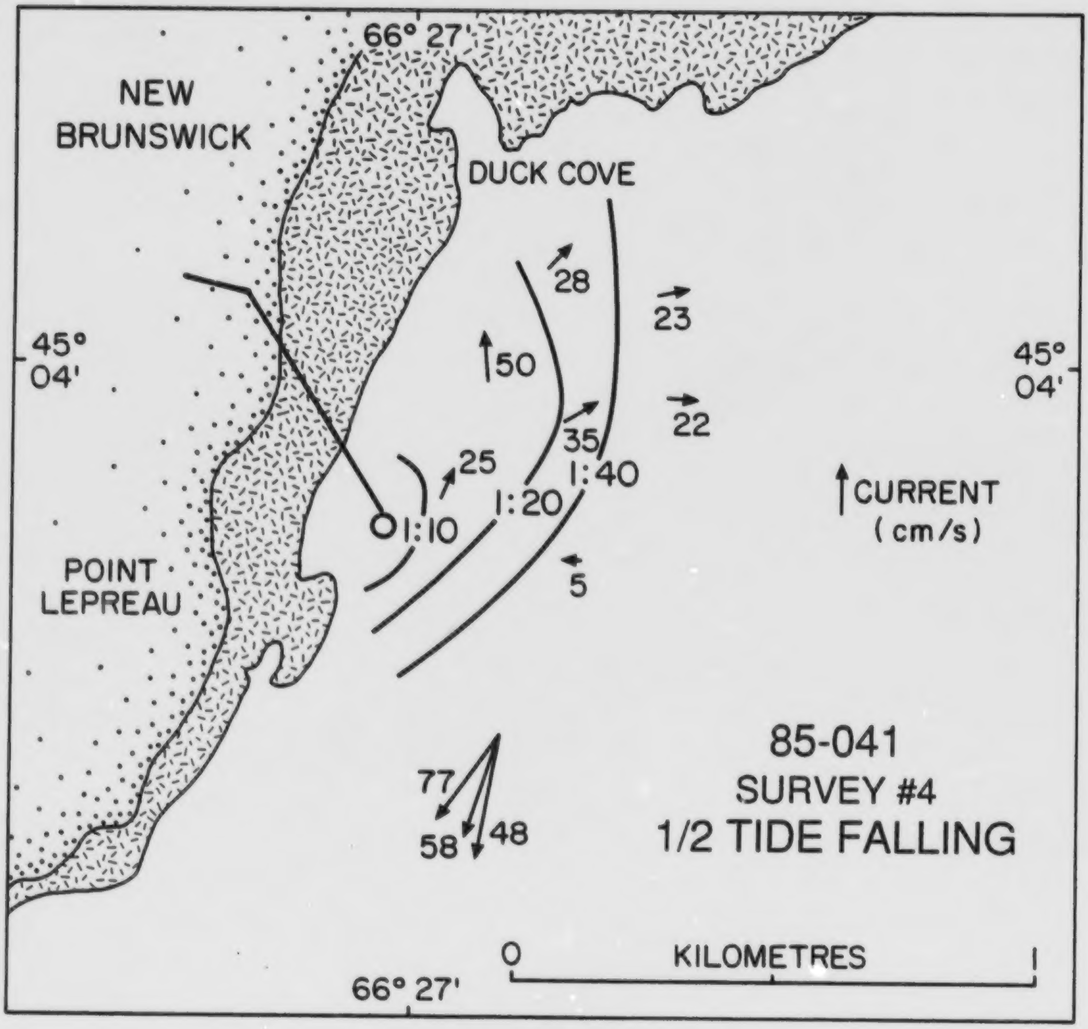

66° 27'
NEW BRUNSWICK
DUCK COVE
45° 04'
45° 04'
28
23
50
22
35
25
1:40
1:20
1:10
CURRENT (cm/s)
POINT LEPREAU
5
85-041
SURVEY #4
1/2 TIDE FALLING
77
58
48
0
KILOMETRES
1
66° 27'

**Figure 15.** Surface current vectors and dilution contours for the ½tide falling survey, 85-041.

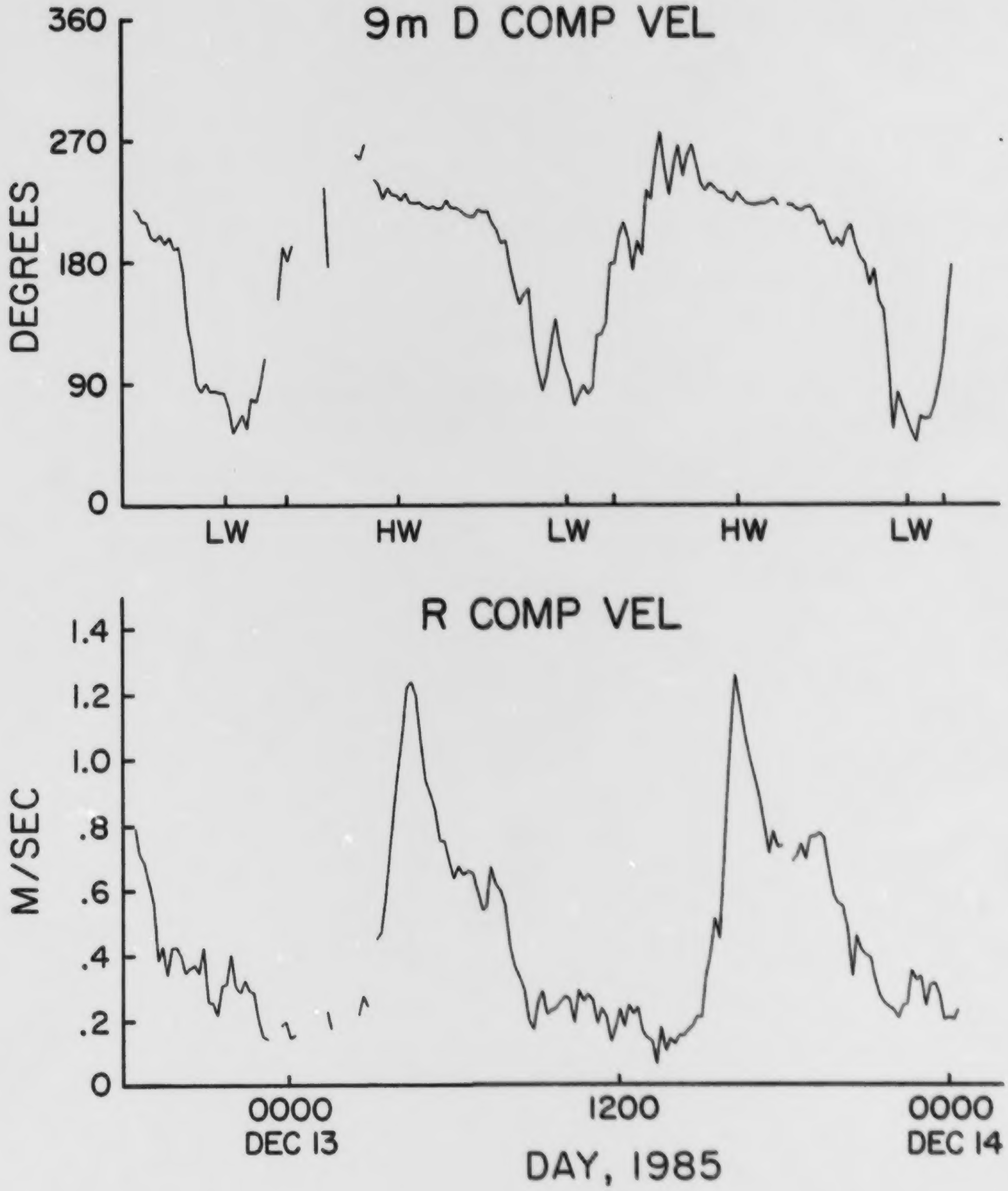


**Figure 16.** Current observed at the CSS Dawson at a depth of 9 meters during the thermal plume survey 85-041.

In contrast, during the low water survey, significantly elevated surface temperatures were observed. The temperature contours exhibited in Figure 18 compare very well with the high temperatures observed during other surveys at this stage of the tide. Surface temperatures and tritium values were highly correlated as shown in Figure 20. Bottom water samples and samples with temperatures near the assumed ambient level of about 2.5°C, showed essentially background tritium values indicating that waters near the point had been completely replaced since the survey on February 25th perhaps due in part to the strong winds that occurred on February 26th. The least squares fit line shown in Figure 20 indicates that the expected outfall tritium activity would be 42 Bq/ℓ assuming an outfall temperature of 23.5°C. Data from NBEPC's Liquid Effluent Monitoring Program for March can be used to calculate an approximate concentration of tritium at the outfall (multiply the monthly %DEL for March by the monthly DEL (Bq) and divide by the monthly cooling water outflow). The calculated tritium activity for March was 60 Bq/ℓ which is comparable to the expected outfall activity of 42 Bq/ℓ assuming that conditions at the end of February approximate those for March.

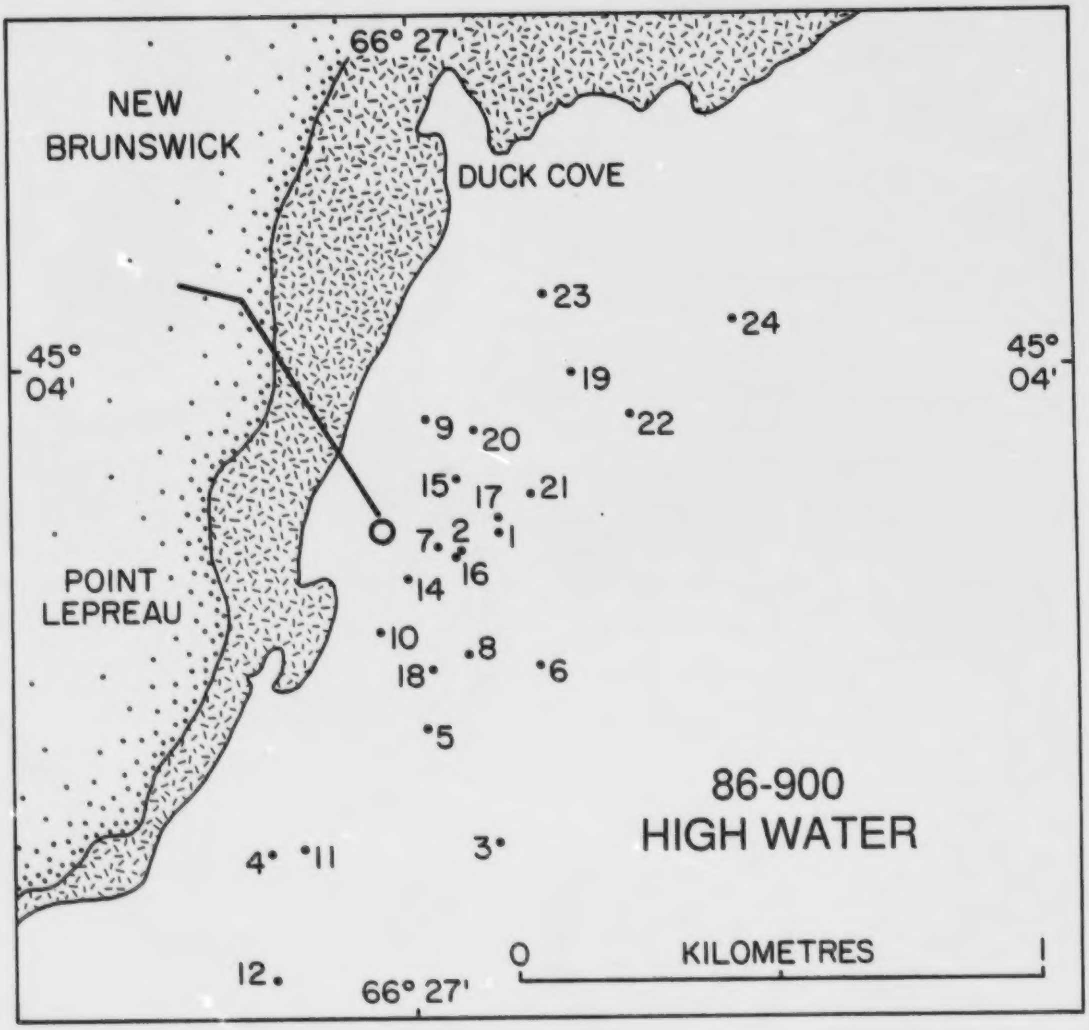

66° 27'
NEW BRUNSWICK
DUCK COVE
•23
•24
45° 04'
•19
•22
45° 04'
•9
•20
15•
17
•21
7•
2
•1
16
•14
POINT LEPREAU
•10
•8
18•
•6
•5
86-900
HIGH WATER
4•
•11
3•
12•
66° 27'
0
KILOMETRES
1

Figure 17. Station locations for the high water survey 86-900.

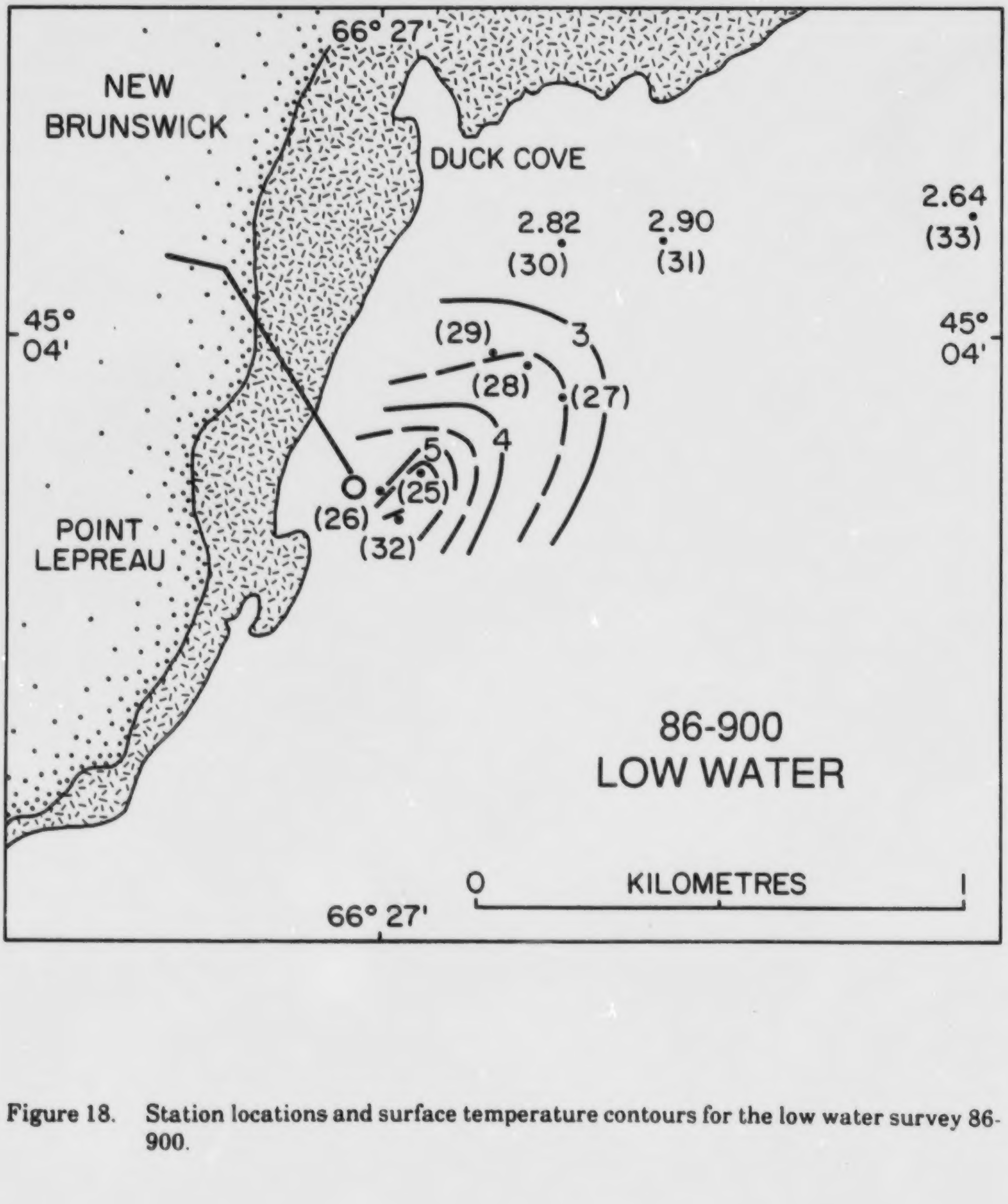

66° 27'
NEW
BRUNSWICK
DUCK COVE
2.82
(30)
2.90
(31)
2.64
(33)
45°
04'
45°
04'
(29)
3
(28)
(27)
4
5
(25)
(26)
(32)
POINT
LEPREAU
86-900
LOW WATER
0
KILOMETRES
1
66° 27'

**Figure 18.** Station locations and surface temperature contours for the low water survey 86-900.

Table 10. Station locations, depths and times accompanied by discreet sampling observations for Survey 86 900

| SAMPLE ID | STATION | DEPT (m) | SAMPLE DEPTH (m) | H-3 (Bq/ℓ) | SALINITY (‰) | T °C | LATITUDE | LONGITUDE | GMT | DATE | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 85-02701 | 1 | 29 | 1 | 6.3 ± 3.0 | 31.69 | 2.00 | 45°3.83'N | 66°26.87'W | 16:21 | 25-2-85 | HW-1610 GMT |
| -02702 | | | 22 | 5.2 ± 3.0 | 31.82 | 2.53 | | 66°26.93'W | | | |
| 02703 | 2 | 24 | 1 | 2.6 ± 2.9 | 31.68 | 2.03 | 45°3.82'N | | 16:30 | " | |
| 02704 | | | 19 | 6.9 ± 3.0 | 31.78 | 2.47 | | | | | |
| 02705 | 3 | 47 | 1 | 5.4 ± 3.0 | 31.56 | 1.93 | 45°3.51'N | 66°26.88'W | 16:40 | " | |
| -02706 | | | 42 | 6.8 ± 2.7 | 32.04 | 2.30 | | | | | |
| -02707 | 4 | 30 | 1 | 4.7 ± 3.0 | 31.69 | 2.51 | 45°3.50'N | 66°27.2'W | 16:50 | " | |
| 02708 | | | 25 | 5.5 ± 3.0 | 31.94 | 2.21 | | | | | |
| -02709 | 5 | 37 | 1 | 3.1 ± 2.9 | 31.75 | 2.05 | 45°3.63'N | 66°26.98'W | 17:00 | " | |
| -- | | | 30 | -- | 32.03 | | | | | | |
| -02710 | 6 | 38 | 1 | <4.25 | 31.69 | 1.99 | 45°3.69'N | 66°26.82'W | 17.11 | " | |
| -02711 | | 36 | 36 | 2.8 ± 2.9 | 32.07 | 2.30 | | | | | |
| -02712 | 7 | 24 | 1 | 2.5 ± 2.9 | 31.71 | 2.04 | 45°3.82'N | 66°26.96'W | 17:20 | " | |
| -02713 | | | 19 | 6.5 ± 3.0 | 31.94 | 2.45 | | | | | |
| -02714 | 8 | 31 | 1 | 3.9 ± 3.0 | 31.63 | 1.98 | 45°3.70'N | 66°26.92'W | 17:26 | " | |
| -02715 | | | 27 | 3.7 ± 3.0 | 31.99 | 2.25 | | | | | |
| -02716 | 9 | 15 | 1 | 3.4 ± 3.0 | 31.51 | 1.92 | 45°3.95'N | 66°26.98'W | 17:36 | " | |
| | | | 10 | | 31.65 | 2.00 | | | | | |
| -02717 | 10 | 20 | 1 | 3.7 ± 3.0 | 31.59 | 3.17 | 45°3.72'N | 66°27.05'W | 17:42 | " | |

Table 10 (Cont'd): Station locations, depths and times accompanied by discreet sampling observations for Survey 86 900

| SAMPLE ID | STATION | DEPT (m) | SAMPLE DEPTH (m) | H-3 (Bq/ℓ) | SALINITY (‰) | T°C | LATITUDE | LONGITUDE | GMT | DATE | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 02718 | | | 18 | 5.4 ± 3.0 | 31.64 | 2.30 | | | | | |
| 02719 | 11 | 29 | 1 | 3.8 ± 3.0 | 31.62 | 2.07 | 45°3.50'N | 66°27.16'W | 17:48 | " | |
| 02720 | | | 24 | 4.1 ± 3.0 | 31.87 | 2.14 | | | | | |
| 02721 | 12 | 44 | 1 | 3.6 ± 3.0 | 31.43 | 1.72 | 45°3.36'N | 66°27.21'W | 17:56 | " | |
| 02722 | | | 36 | 5.7 ± 3.0 | 31.90 | 2.16 | | | | | |
| 0272 | 13 | 18 | 1 | 5.7 ± 3.0 | 31.57 | 1.80 | 45°3.80'N | 66°27.94'W | 18:10 | " | |
| 02724 | | | 18 | 4.2 ± 3.0 | 31.69 | 2.00 | | | | | |
| 02725 | 14 | 13 | 1 | 4.9 ± 3.0 | 31.59 | 2.10 | 45°3.78'N | 66°27.03'W | 19:01 | " | |
| 02726 | | | 9 | 2.9 ± 3.0 | | 2.01 | | | | | |
| 02727 | 15 | 21 | 1 | 7.2 ± 3.0 | 31.71 | 2.07 | 45°3.88'N | 66°26.95'W | 19:06 | " | |
| 02728 | | | 17 | 3.2 ± 3.0 | 31.67 | 2.06 | | | | | |
| 02729 | 16 | 22 | 1 | 5.0 ± 3.0 | 31.57 | 2.55 | 45°3.82'N | 66°26.96'W | 19:12 | " | |
| 02730 | | | 14 | 5.5 ± 3.0 | 31.61 | 2.92 | | | | | |
| 02731 | 17 | 29 | 1 | 4.9 ± 3.0 | 31.53 | 1.98 | 45°3.84'N | 66°26.90'W | 19:19 | " | |
| 02732 | | | 24 | <3.6 | 31.89 | 2.19 | | | | | 1/2 falling 1918 GMT |
| 02733 | 18 | 24 | 1 | 4.4 ± 3.0 | 31.61 | 2.04 | 45°3.68'N | 66°26.99'W | 19:26 | " | intake |
| 02734 | | | 18 | 6.1 ± 3.0 | 31.71 | 2.10 | | | | | |
| 02735 | 19 | 20 | 1 | 6.4 ± 3.0 | 31.81 | 2.15 | 45°4.00'N | 66°26.79'W | 19:36 | " | |
| 02736 | | | 17 | 5.4 ± 3.0 | 31.84 | 2.17 | | | | | ←start of pumpout |

Table 10 (Cont'd) Station locations, depths and times accompanied by discrete sampling observations for Survey 86 900

| SAMPLE ID | STATION | DEPT (m) | SAMPLE DEPTH (m) | H-3 (Bq/ℓ) | SALINITY (‰) | T °C | LATITUDE | LONGITUDE | GMT | DATE | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| -02737 | 20 | 11 | 1 | 8.6 ± 3.0 | 31.74 | 2.10 | 45°3.93'N | 66°26.94'W | 19:41 | " | |
| -02738 | | | 11 | 5.3 ± 3.0 | 31.75 | 2.11 | | | | | |
| -02739 | 21 | 27 | 1 | 4.3 ± 3.0 | 31.89 | 2.30 | 45°3.87'N | 66°26.85'W | 19:50 | " | |
| -02740 | | | 22 | 6.6 ± 3.0 | 31.85 | 2.17 | | | | | |
| -02741 | 22 | 25 | 1 | 5.3 ± 3.0 | 31.93 | 2.23 | 45°3.95'N | 66°26.71'W | 19:57 | " | |
| -02742 | | | 22 | 6.2 ± 3.0 | 31.94 | 2.24 | | | | | |
| 02743 | 23 | 15 | 1 | 5.1 ± 3.0 | 31.71 | 2.18 | 45°4.08'N | 66°26.84'W | 20:03 | " | |
| -02744 | | | 13 | 9.3 ± 3.0 | 31.77 | 2.13 | | | | | |
| -02745 | 24 | 24 | 1 | 2.8 ± 3.0 | 31.81 | 2.12 | 45°4.06'N | 66°26.56'W | 20:09 | " | |
| -02746 | | | 22 | 3.3 ± 2.9 | 31.96 | 2.25 | | | | | |
| -02747 | 25 | 15 | 1 | 8.5 ± 3.0 | 32.18 | 5.73 | 45°3.84'N | 66°26.96'W | 12:04 | 25-2-86 | 1125 LW |
| -02748 | | | 14 | < 3.7 | 32.32 | 2.88 | | | | | |
| 02749 | 26 | 16 | 1 | 5.2 ± 3.0 | 32.11 | 4.90 | 45°3.82'N | 66°27.02'W | 12:12 | " | |
| -02750 | | | 19 | Lc = 2.4 | 32.43 | 3.08 | | | | | |
| -02751 | 27 | 20 | 1 | 3.8 ± 2.9 | 32.32 | 3.62 | 45°3.93'N | 66°26.74'W | 12:19 | " | |
| -02752 | | | 17 | 3.5 ± 2.9 | 32.44 | 3.12 | | | | | |
| -02753 | 28 | 20 | 1 | 8.0 ± 3.0 | 32.25 | 3.69 | 45°3.97'N | 66°26.80'W | 12:26 | " | |
| -02754 | | | 17 | < 4.3 | -- | 3.09 | | | | | |
| -02755 | 29 | 13 | 1 | 4.8 ± 3.0 | 32.32 | 3.15 | 45°3.98'N | 66°26.85'W | 12:33 | 27-2-86 | |

Table 10 (Cont'd): Station locations, depths and times accompanied by discreet sampling observations for Survey 86 900.

| SAMPLE ID | STATION | DEPT (m) | SAMPLE DEPTH (m) | H-3 (Bq/ℓ) | SALINITY (‰) | T °C | LATITUDE | LONGITUDE | GMT | DATE | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| -02756 | | | 12 | 3.5 ± 2.9 | -- | 3.03 | | | | | |
| -02757 | 30 | 14 | 1 | Lc = 2.2 | 32.32 | 2.82 | 45°4.10'N | 66°26.75'W | 12:39 | " | |
| -02758 | | | 9 | < 3.0 | 32.37 | 2.95 | | | | | |
| -02159 | 31 | 18 | 1 | Lc = 2.2 | 32.32 | 2.90 | 45°4.10'N | 66°26.59'W | 12:44 | " | |
| -02160 | | | 15 | 2.7 ± 2.9 | 32.39 | 3.01 | | | | | |
| -02161 | 32 | 21 | 1 | 8.7 ± 3.0 | 32.24 | 5.13 | 45°3.79'N | 66°26.99'W | 12:55 | " | |
| 02162 | | | 21 | Lc = 2.4 | 32.45 | 3.14 | | | | | |
| 02163 | 33 | 25 | 1 | Lc = 2.4 | 32.25 | 2.64 | 45°4.14'N | 66°26.11'W | 13:11 | " | |
| -02164 | | | 24 | < 2.8 | 32.45 | 3.14 | | | | | |

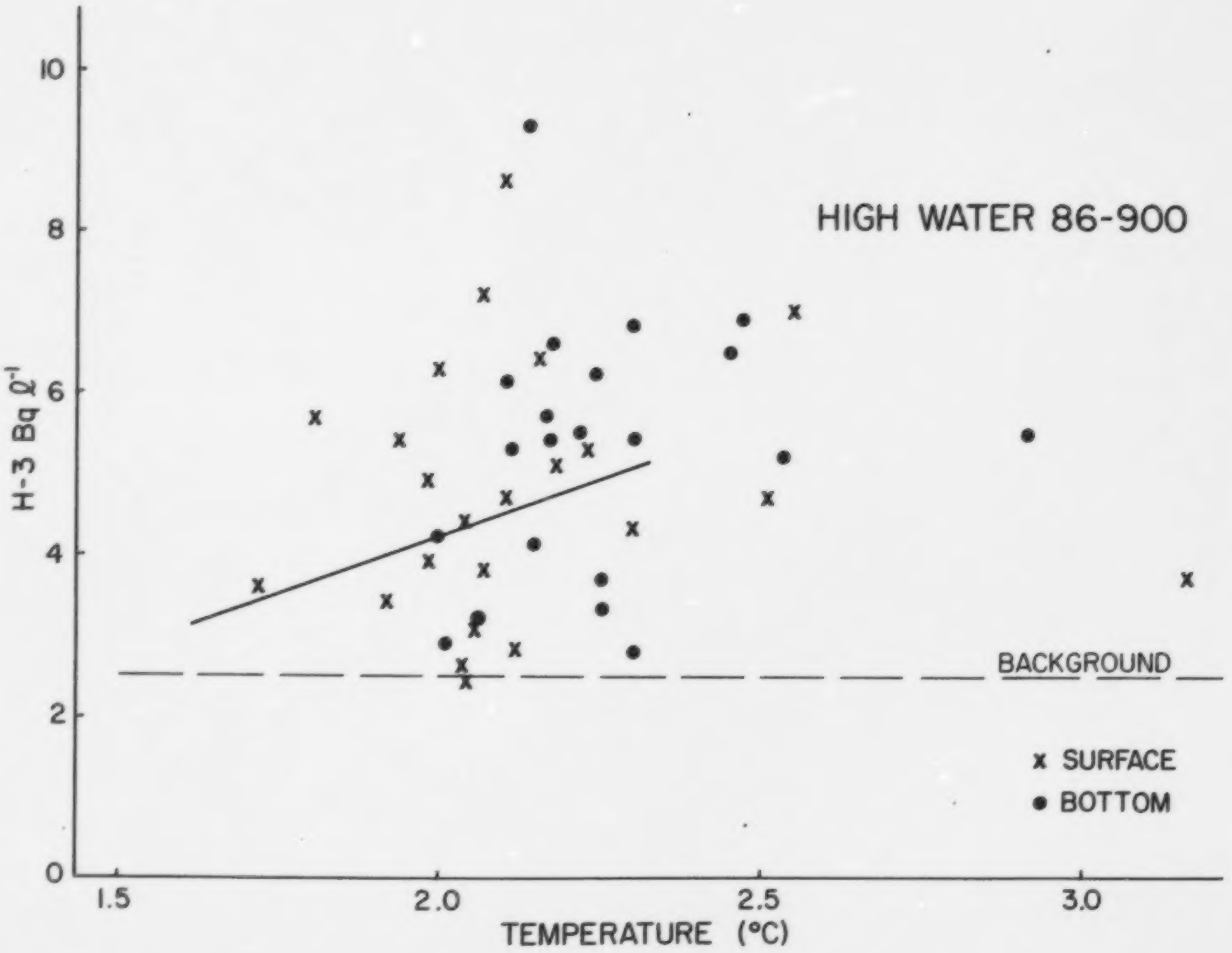


Figure 19. Temperature tritium diagram for the high water survey 86-900.

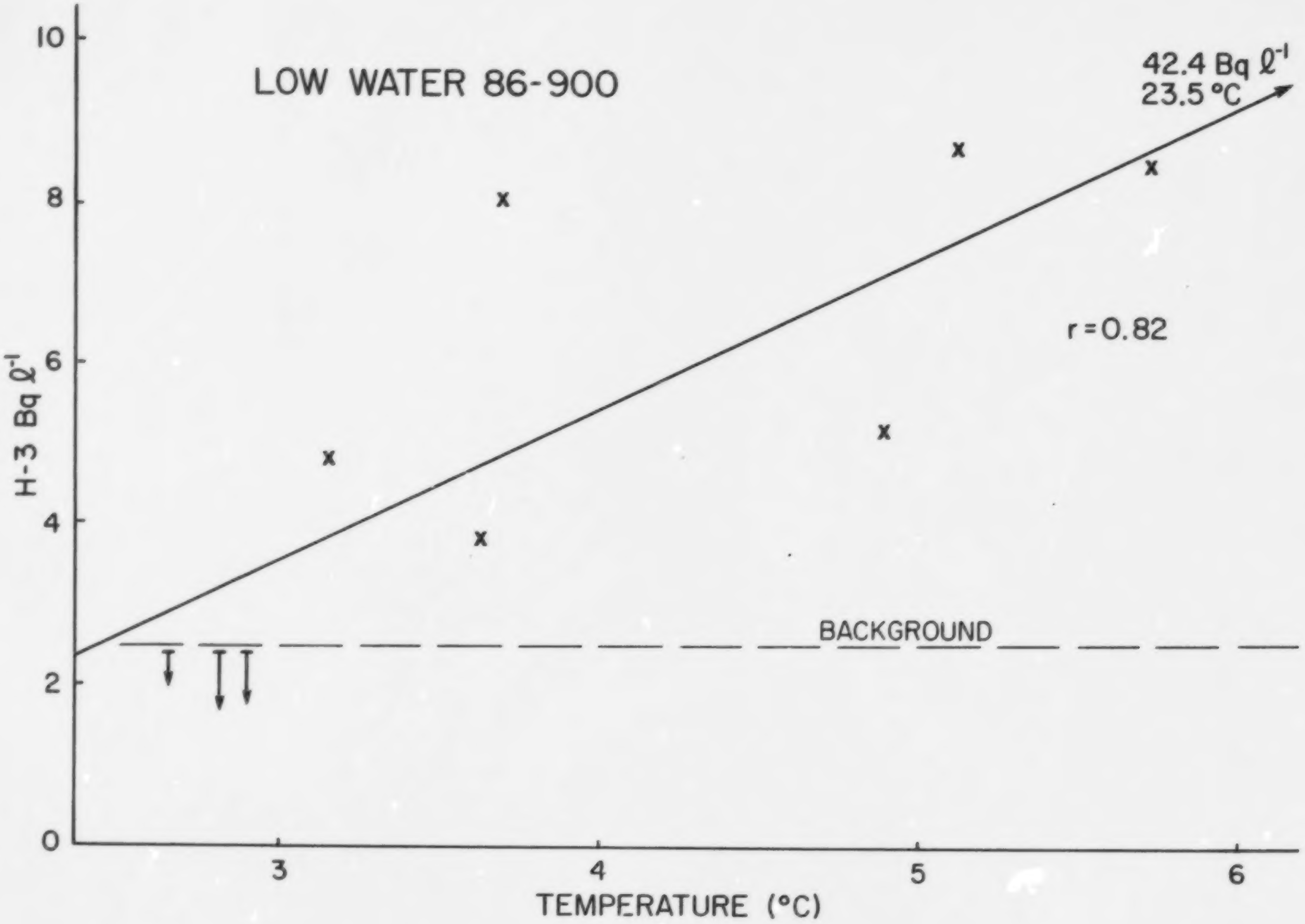


Figure 20. Temperature tritium diagram for the low water survey 86-900. The line represents a least squares fit of the data ($r = 0.82$) and the projected outfall tritium concentration assuming a condenser temperature rise of 21 °C is shown.

## 3.0 ATMOSPHERIC MONITORING

The atmosphere is the most dynamic environmental medium for the transport of gaseous and particulate emissions from nuclear power generating facilities. Effective dispersion of gaseous or finely divided material released into the atmosphere near the ground depends on various natural mixing processes. Mainly, this mixing is a direct consequence of turbulent and convective motions generated in the boundary layer itself. Mixing in the boundary layer is dependent partly on the aerodynamic friction of the underlying surface and on the density stratification of the air which results from differences in surface and air temperature. Temperature differences arise over land primarily in the course of the daily cycle of radiative heating and cooling of the ground but may also arise from the influx of air from warmer or cooler regions of the earth (Pasquill *et al.* 1983). The dispersion of radionuclides released via stack gas emissions follows several pathways; direct deposition, transport via air movement and subsequent exchange with surface water, and transfer to various media via precipitation of airborne particulates.

The two principal components of the atmospheric monitoring program at Point Lepreau are (1) the ongoing compilation of a meteorological data base for the Point Lepreau region which can be applied in the projection of the transport of airborne pollutants under diverse weather conditions and in atmospheric transport models, and (2) the collection of atmospheric water vapour and air particulate samples for radionuclide analysis.

### 3.1 Meteorological Data Collection

The meteorological data collection station was established in 1978 at Hall's Lake Siding and was moved in 1983 three kilometers east to the New Brunswick Department of Transport depot at Musquash to facilitate equipment maintenance. The station consists of (1) U2A wind equipment to measure wind speed and direction 10 meters above ground level, (2) Fischer and Porter precipitation gauge and (3) a thermohygrograph to record temperature and relative humidity. An additional change was made in May 1986 when NBEPC agreed to provide 10 meter wind speed and direction data from an on site tower at the NGS which provides AERU with a more accurate assessment of wind conditions at the site of releases from the NGS.

The Atmospheric Environment Service extracts wind, temperature, rainfall and relative humidity data for use in the monitoring program. Wind speed data for 1985/86 are presented in Tables 11 and 12. There are several notable differences from 1985 to 1986, (1) an increase in the average wind speed from 4.5 knots in 1985 to 6.4 knots in 1986 and (2) a decrease in the percent calm hours from 13% in 1985 to 7% in 1986. Both changes are related to the shift in use of wind data from the Musquash site to the Point Lepreau site. Comparison of data from both sites for the six month period from May to October 1986 showed that the average windspeed for Point Lepreau was twice the average for Musquash (6.6 knots compared to 3.3 knots) and the percentage of calm hours was 17% at Musquash compared to 3% at Point Lepreau (Beattie, personal communication).

Precipitation data for 1985/86 from three sites at Saint John airport, Musquash and Colson Cove are presented in Table 13. There was a 13% decrease in precipitation amounts from 1984 to 1985 and a further 2% decrease from 1985 to 1986 at Saint John airport. As noted in previous years, there were higher precipitation amounts recorded at Saint John airport than at Musquash (Nelson *et al.* 1986).

## 3.2 Air Monitoring Results

AERU operates a network of five air monitoring stations at locations shown in Figure 21. The air monitoring stations are constructed as illustrated in Figure 22 and have been described previously (Bishop *et al.* 1980). Three of the stations located at Point Lepreau Lighthouse, Dipper Harbour and Mace's Bay are adjacent to stations owned and operated by NBEPC and Health and Welfare Canada (HWC) allowing for a comparison of data. The fourth is located in Musquash, 15 km north of the NGS and a fifth station is in Digby, N.S.

Table 11. Mean wind speed (knots) and percent frequency of wind direction from U2A wind sensor at Point Lepreau, N.B. during 1985. Station is located at Musquash, N.B.

| Direction | January - March | | April - June | | July - September | | October - December | | Annual | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Percent Frequency | Mean Speed | Percent Frequency | Mean Speed | Percent Frequency | Mean Speed | Percent Frequency | Mean Speed | Percent Frequency | Mean Speed |
| N | 5.3% | 3.7 | 4.3% | 4.8 | 2.8% | 4.3 | 3.1% | 3.2 | 3.8% | 4.1 |
| NNE | 1.8% | 2.7 | 5.1% | 6.7 | 3.5% | 5.9 | 4.7% | 5.3 | 3.9% | 5.7 |
| NE | 3.7% | 4.2 | 8.7% | 7.8 | 3.4% | 4.8 | 4.1% | 6.4 | 5.0% | 6.4 |
| ENE | 2.8% | 3.5 | 5.4% | 5.8 | 2.2% | 4.1 | 0.5% | 2.7 | 2.8% | 4.8 |
| E | 1.1% | 2.9 | 4.2% | 5.3 | 2.3% | 3.1 | 1.7% | 4.0 | 2.4% | 4.3 |
| ESE | 0.8% | 6.4 | 5.4% | 4.6 | 3.9% | 3.2 | 2.0% | 4.1 | 3.2% | 4.1 |
| SE | 3.2% | 7.5 | 3.5% | 4.1 | 3.5% | 3.6 | 2.1% | 3.0 | 3.1% | 4.5 |
| SSE | 0.9% | 2.3 | 2.6% | 4.5 | 4.0% | 3.2 | 3.3% | 3.9 | 2.8% | 3.7 |
| S | 0.9% | 3.0 | 6.0% | 6.0 | 7.7% | 4.6 | 2.3% | 5.0 | 4.5% | 5.1 |
| SSW | 1.6% | 4.8 | 8.5% | 6.3 | 9.3% | 5.2 | 3.0% | 6.4 | 5.9% | 5.7 |
| SW | 4.5% | 4.4 | 10.5% | 7.1 | 14.5% | 5.9 | 4.6% | 5.6 | 8.9% | 6.1 |
| WSW | 7.9% | 4.8 | 10.0% | 6.6 | 11.8% | 5.2 | 6.5% | 4.0 | 9.2% | 5.3 |
| W | 9.7% | 4.5 | 6.0% | 4.5 | 9.7% | 4.2 | 12.4% | 4.2 | 9.4% | 4.3 |
| WNW | 11.5% | 5.6 | 7.2% | 7.4 | 7.5% | 4.3 | 14.1% | 4.3 | 9.9% | 5.2 |
| NW | 9.9% | 5.5 | 8.1% | 6.2 | 7.2% | 4.9 | 9.6% | 5.6 | 8.6% | 5.6 |
| NNW | 6.4% | 5.5 | 4.5% | 4.7 | 2.4% | 4.1 | 2.9% | 2.9 | 3.9% | 4.5 |
| Calm | 28.0% | 0.0 | 0.1% | 0.0 | 4.4% | 0.0 | 23.0% | 0.0 | 12.8% | 0.0 |
| Mean Speed (Knots) | | 3.9 | | 6.0 | | 4.4 | | 3.7 | | 4.5 |

Table 12. Mean speed (knots) and percent frequency of wind direction from Point Lepreau, N.B.during 1986. Station is located at Musquash, N.B., January to April and at the NGS May to December.

| Direction | January - March | | April - June | July - September | October - December | Annual |
|---|---|---|---|---|---|---|
| | Percent Frequency | Mean Speed | | | | |
| N | 4.4% | 4.6 | 3.9% | 4.3% | 6.9% | 4.9% |
| NNE | 4.9% | 5.8 | 6.2% | 3.9% | 7.6% | 5.7 |
| NE | 4.8% | 4.5 | 5.1% | 7.0% | 2.7% | 4.8% |
| ENE | 2.3% | 5.1 | 7.7% | 6.4% | 2.0% | 4.5% |
| E | 1.9% | 4.9 | 4.3% | 3.2% | 1.8% | 2.8% |
| ESE | 2.0% | 6.4 | 2.1% | 2.6% | 2.1% | 2.2% |
| SE | 2.9% | 6.9 | 1.9% | 1.8% | 2.0% | 2.1% |
| SSE | 1.6% | 6.4 | 2.3% | 4.0% | 2.8% | 2.7% |
| S | 4.4% | 6.7 | 7.8% | 6.8% | 2.9% | 5.4% |
| SSW | 4.2% | 5.8 | 12.7% | 14.3% | 7.0% | 9.5% |
| SW | 5.2% | 5.1 | 12.5% | 13.0% | 8.1% | 9.6% |
| WSW | 6.7% | 5.7 | 7.2% | 8.6% | 8.5% | 7.7% |
| W | 9.4% | 5.8 | 6.4% | 8.2% | 9.6% | 8.5% |
| WNW | 13.6% | 5.3 | 4.5% | 4.9% | 9.1% | 8.1% |
| NW | 10.4% | 5.3 | 5.4% | 5.9% | 12.2% | 8.6% |
| NNW | 3.7% | 3.5 | 2.0% | 4.0% | 14.3% | 6.2% |
| Calm | 17.6% | 0.0 | 8.0% | 0.9% | 0.4% | 6.7% |
| Mean Speed (Knots) | | 4.5 | 5.7 | 6.2 | 9.1 | 6.4 |

Table 13. Comparison of monthly precipitation in millimeters at stations located in Saint John, Coleson Cove and Musquash, N.B. for 1985, 1986.

| Month | Saint John (mm) | Coleson Cove (mm) | Musquash (mm) |
|---|---|---|---|
| January | 44 | 21 | 81 |
| February | 107 | 74 | 69 |
| March | 110 | 77 | 58 |
| April | 48 | 53 | 251 |
| May | 197 | 192 | 119 |
| June | 269 | 228 | -- |
| July | 42 | 43 | -- |
| August | 89 | 84 | -- |
| September | 34 | 32 | -- |
| October | 97 | 67 | -- |
| November | 136 | 123 | 163 |
| December | 123 | 92 | 91 |
| Total (1985) | 1296 | 1086 | *** |
| January | 135 | 97 | 132 |
| February | 61 | 66 | 30 |
| March | 138 | 114 | 127 |
| April | 128 | 120 | 104 |
| May | 77 | 66 | 71 |
| June | 73 | 64 | 38 |
| July | 68 | 82 | 97 |
| August | 193 | 156 | 147 |
| September | 93 | 93 | 91 |
| October | 50 | 52 | 53 |
| November | 145 | 135 | 135 |
| December | 111 | 84 | 79 |
| Total (1986) | 1271 | 1130 | 1105 |

Note: Monthly total may not sum to the annual total due to round off when converting from inches to millimeters.

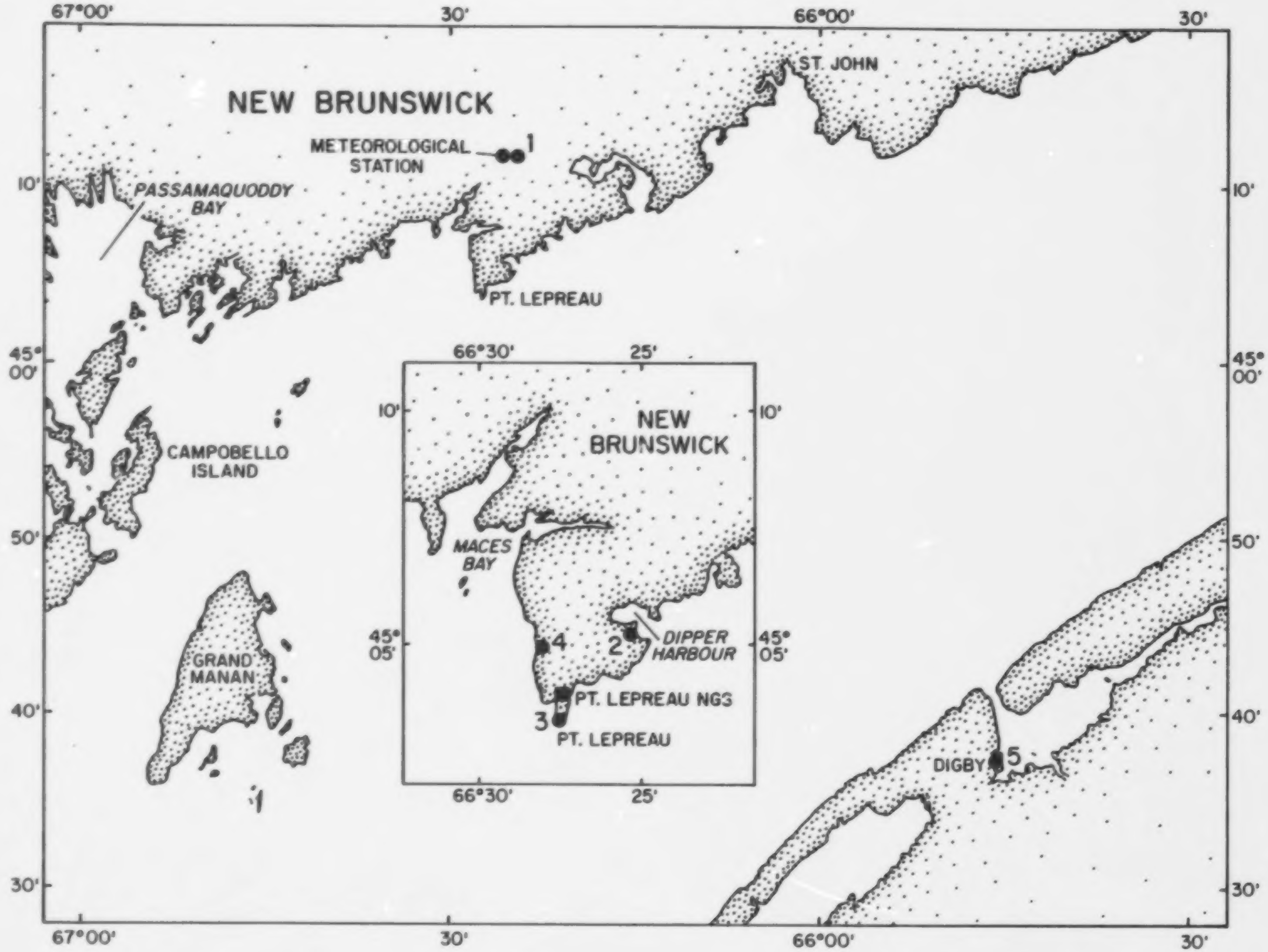

67°00'
30'
66°00'
30'
10'
45° 00'
50'
40'
30'
NEW BRUNSWICK
METEOROLOGICAL STATION
1
PASSAMAQUODDY BAY
ST. JOHN
PT. LEPREAU
CAMPOBELLO ISLAND
GRAND MANAN
DIGBY
5
66°30'
25'
10'
45° 05'
NEW BRUNSWICK
MACES BAY
4
2
DIPPER HARBOUR
PT. LEPREAU NGS
3
PT. LEPREAU

Figure 21. Air monitoring station locations.

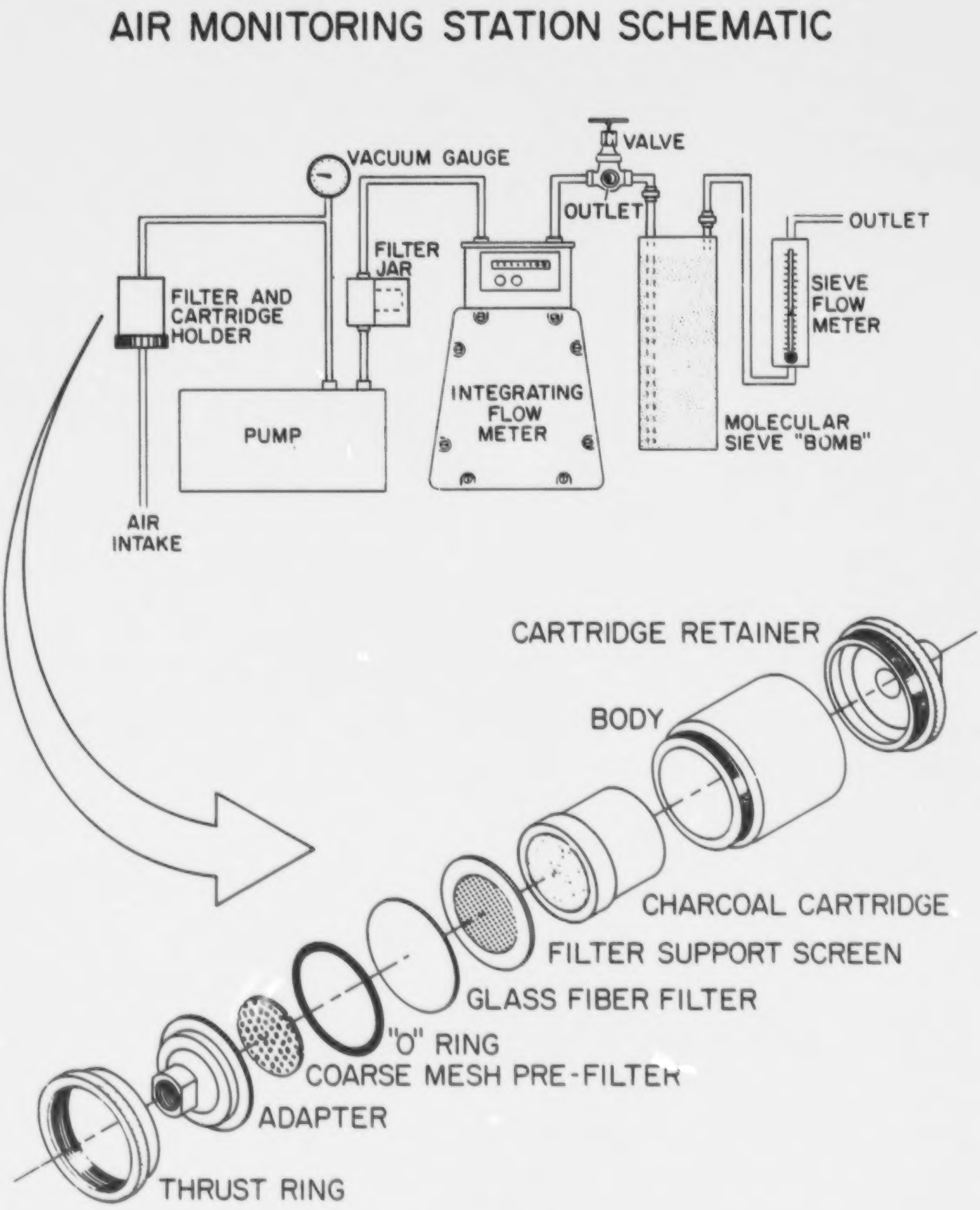

AIR MONITORING STATION SCHEMATIC
VALVE
VACUUM GAUGE
OUTLET
OUTLET
FILTER JAR
FILTER AND CARTRIDGE HOLDER
SIEVE FLOW METER
INTEGRATING FLOW METER
PUMP
MOLECULAR SIEVE "BOMB"
AIR INTAKE
CARTRIDGE RETAINER
BODY
CHARCOAL CARTRIDGE
FILTER SUPPORT SCREEN
GLASS FIBER FILTER
"O" RING
COARSE MESH PRE-FILTER
ADAPTER
THRUST RING

Figure 22. Schematic diagram of air monitoring station used in the field to collect water vapour (on molecular sieve), particulates (glass fiber filter), and I-131 (on charcoal cartridge).

The Digby station is positioned to assess the magnitude of airborne radionuclide transport across the Bay of Fundy.

The approximate detection limits are 4E-5 mBq/m$^3$ for particulate Cs-137, 3E-2 mBq/m$^3$ for I-131 on the charcoal cartridge and 1E-2 Bq/m$^3$ for H-3 in water vapour. The detection limits assume a decay interval of ten days between sampling and analysis and will vary depending on sampling and instrumental parameters.

### 3.2.1 Tritium Results

The five air monitoring stations have operated without problems through 1985/86. Sampling periods ranged from 6 to 18 days per month and an average of 808 m$^3$ of air was drawn through the filters. Water was distilled from the molecular sieve material and analyzed for tritium following the procedures outlined in Bishop *et al.* (1980).

The tritium activities calculated in terms of air moisture are presented in Figures 23 to 25 and Table 14 for the years 1984/85/86. The results show the general increase in tritium activities observed in the Point Lepreau area over the last few years. The average tritium activity measured for all stations has generally increased ($18 \pm 30$ in 1983; $31 \pm 61$ in 1984; $26 \pm 33$ in 1985 and $45 \pm 78$ Bq/$\ell$ in 1986) in agreement with gaseous effluent pathway emission data which indicate that the amount of tritium released from the NGS has also increased each year (Table 1).

Figures 23, 24 and 25 illustrate the trend of increasing tritium activity in the vicinity of the reactor with even AMS #1 at Musquash, N.B., showing an increase in tritium activity over pre-operational levels. Only the AMS station at Digby has tritium activities remaining at pre-operational levels, revealing no evidence, to date, of the transport of wind borne pollutants across the Bay of Fundy. Figures 26-28 illustrate tritium activities as a function of air volume (Bq/m$^3$). The increase in relative humidity in the summer results in the 'apparent' summer maximum in tritium activity (Bq/$\ell$) observed in previous years (Smith *et al*., 1981, 1982). Converting tritium activity from Bq/m$^3$ of air sampled removes the effects

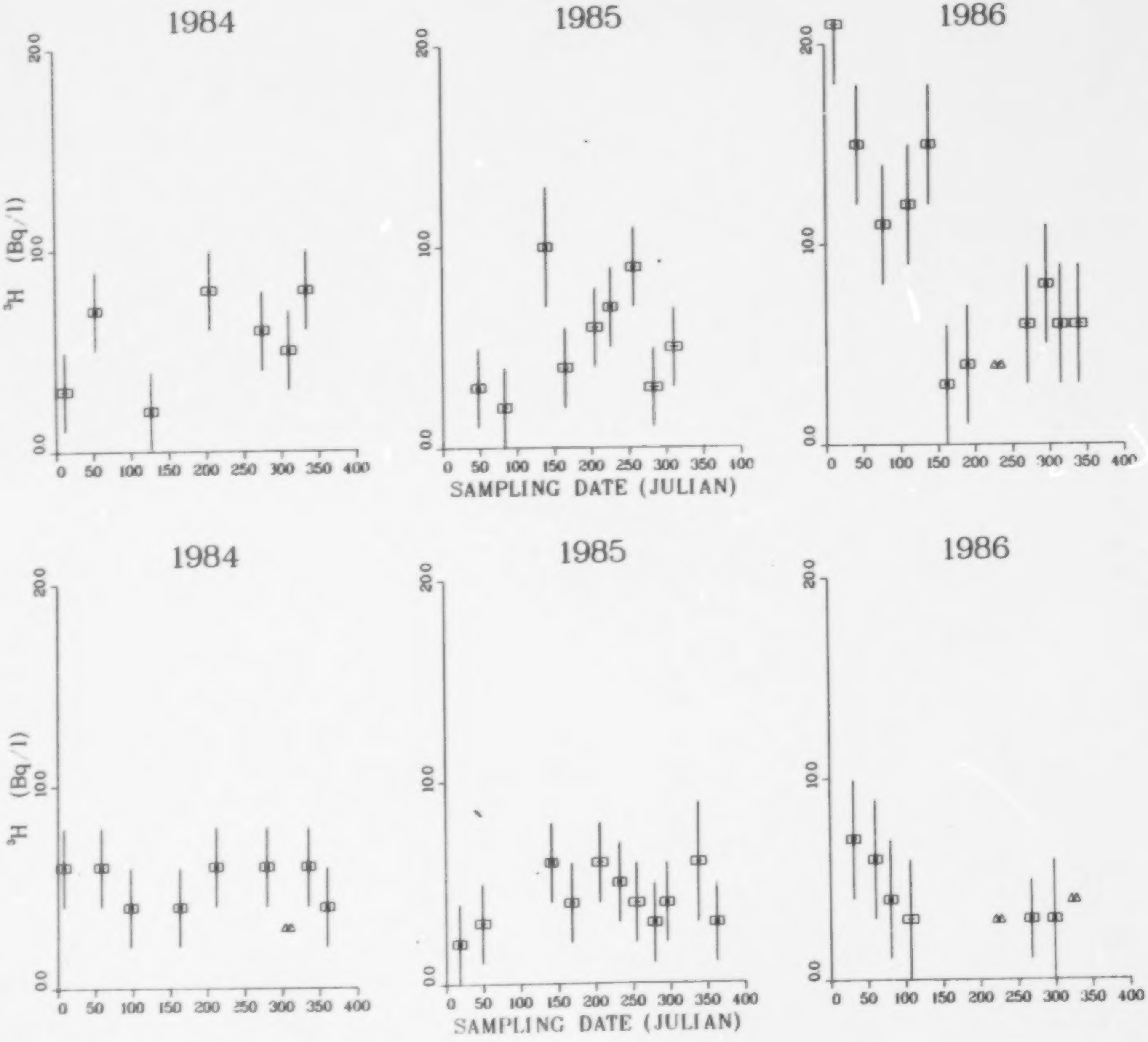


Figure 23. Tritium (Bq/l) as a function of sampling date for air monitoring stations 1 (upper) and 5 (lower) for 1984, 1985 and 1986. Δ-Δ represents tritium values less than the detection limit.

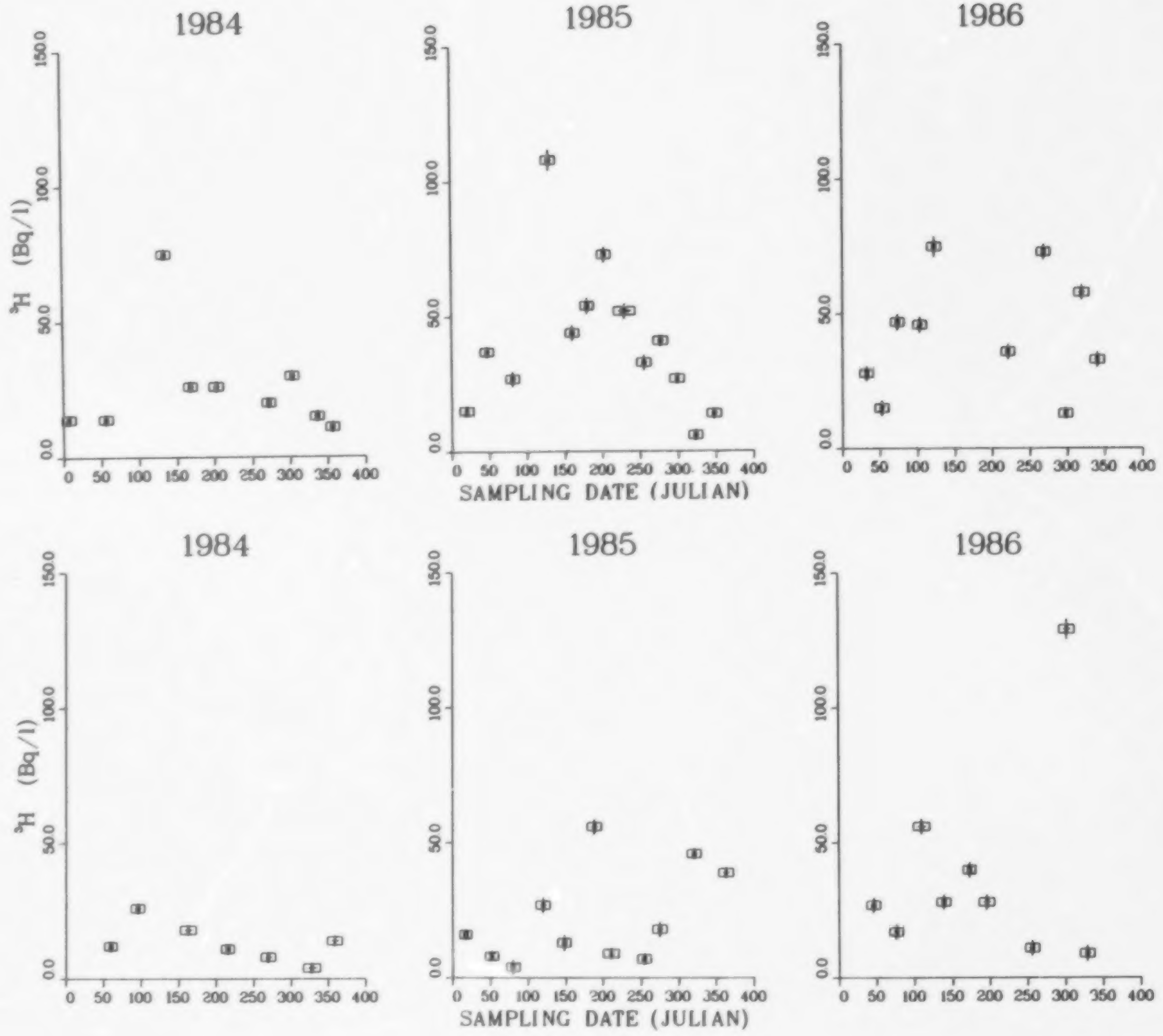


Figure 24. Tritium activity (Bq/l) as a function of sampling date for air monitoring stations 2 (upper) and 4 (lower) for 1984, 1985 and 1986.

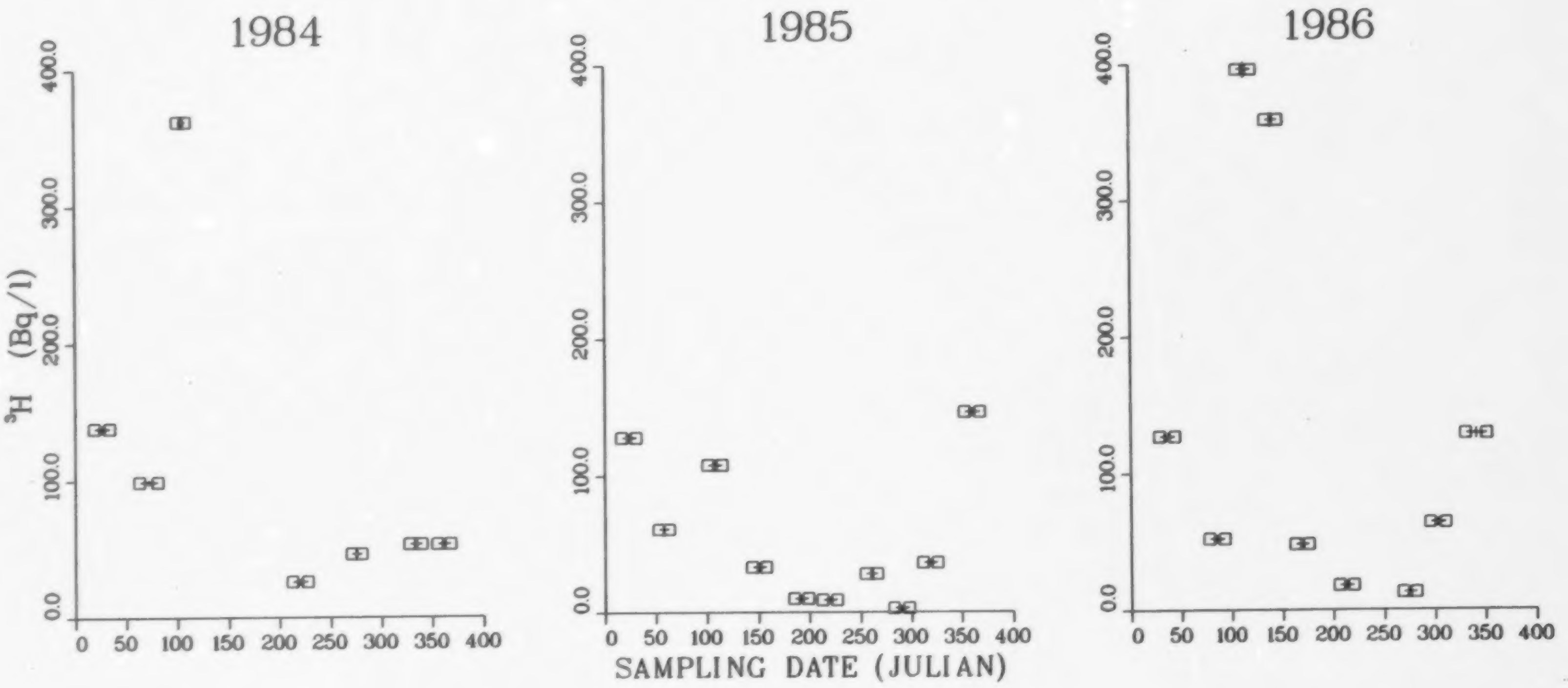


Figure 25. Tritium activity (Bq/l) as a function of sampling date for air monitoring station 3, 1985 and 1986.

Table 14 Radionuclide results for air monitoring stations identified by location numbers shown in Figure 21 for 1985 and 1986 (F, air filter; C, filter cartridge).

| Sample | Stn. # | Sample Date | ABS HUM | H 3 (Bq/l) | H 3 (Bq/m³) | Be-7 (mBq/m³) F | Cs-137 (mBq/m³) F | Cs-134 (mBq/m³) F | Ru-103 (mBq/m³) F | I-131 (mBq/m³) F | I-131 (mBq/m³) C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 84-0942 | 2 | Jan. 20 85 | 1.176 | 15 ± 2 | 0.021 ± .003 | 0.68 ± .09 | <0.03 | | | | |
| 84-0943 | 3 | Jan. 24 85 | 2.149 | 127 ± 3 | 0.020 ± .005 | 1.39 ± .08 | <0.02 | | | | |
| 84-0944 | 4 | Jan. 17 85 | 1.438 | 16 ± 2 | 0.018 ± .003 | 1.94 ± .19 | <0.05 | | | | |
| 84-0945 | 5 | Jan. 18 85 | 1.057 | 2 ± 2 | 0.003 ± .003 | 3.02 ± .15 | <0.03 | | | | |
| 84-0946 | 1 | Feb. 17 85 | 2.088 | 3 ± 2 | 0.011 ± .006 | 2.37 ± .16 | <0.04 | | | | |
| 84-0947 | 2 | Feb. 15 85 | 1.460 | 37 ± 2 | 0.143 ± .008 | 0.28 ± .09 | <0.03 | | | | |
| 84-0948 | 3 | Feb. 27 85 | 1.115 | 60 ± 3 | 0.067 ± .004 | 2.00 ± .08 | <0.01 | | | | |
| 84-0949 | 4 | Feb. 20 85 | 1.565 | 8 ± 2 | 0.028 ± .006 | 2.60 ± .15 | <0.04 | | | | |
| 84-0950 | 5 | Feb. 19 85 | 0.881 | 3 ± 2 | 0.012 ± .006 | 1.99 ± .10 | <0.02 | | | | |
| 84-0951 | 1 | Mar. 24 85 | 2.814 | 2 ± 2 | 0.006 ± .006 | 3.61 ± .11 | <0.02 | | | | |
| 84-0952 | 2 | Mar. 22 85 | 1.880 | 27 ± 3 | 0.050 ± .005 | 1.09 ± .09 | <0.03 | | | | |
| 84-0953 | 3 | Apr. 18 85 | 1.519 | 107 ± 4 | 0.380 ± .010 | -- | -- | | | | |
| 84-0954 | 4 | Mar. 21 85 | 1.899 | 4 ± 2 | 0.007 ± .005 | 4.31 ± .17 | <0.04 | | | | |
| 84-0955 | 5 | Mar. 25 85 | -- | -- | -- | 2.84 ± .14 | <0.03 | | | | |
| 85-2001 | 1 | May 19 85 | 2.665 | 10 ± 3 | 0.08 ± .02 | 3.21 ± .13 | <0.03 | | | | |
| 85-2002 | 2 | May 10 85 | 1.791 | 108 ± 4 | 0.62 ± .02 | 1.51 ± .11 | <0.02 | | | | |
| 85-2004 | 4 | Apr. 30 85 | 3.289 | 27 ± 3 | 0.15 ± .02 | 2.79 ± .15 | <0.04 | | | | |
| 85-2005 | 5 | May 20 85 | 1.336 | 5 ± 2 | 0.05 ± .02 | 2.95 ± .12 | <0.03 | | | | |
| 84-0956 | 3 | Apr. 17 85 | 1.516 | 108 ± 4 | 0.16 ± .01 | 3.15 ± .10 | <0.02 | | | | |
| 85-2006 | 1 | Jun. 13 85 | 6.319 | 4 ± 2 | 0.04 ± .02 | 2.36 ± .12 | <0.03 | | | | |
| 85-2007 | 2 | Jun. 10 85 | 5.390 | 44 ± 3 | 0.38 ± .03 | 0.39 ± .08 | <0.03 | | | | |
| 85-2008 | 3 | May 31 85 | 4.839 | 33 ± 3 | 0.29 ± .02 | 1.82 ± .10 | <0.02 | | | | |
| 85-2009 | 4 | May 28 85 | 3.836 | 13 ± 3 | 0.11 ± .02 | 4.00 ± .19 | <0.04 | | | | |
| 85-2010 | 5 | Jun. 16 85 | 4.299 | 4 ± 3 | 0.04 ± .02 | 1.59 ± .09 | <0.03 | | | | |
| 85-2011 | 1 | Jul. 24 85 | 4.449 | 6 ± 2 | 0.07 ± .03 | 3.74 ± .27 | <0.04 | | | | |
| 85-2012 | 2 | Jun. 29 85 | 6.588 | 54 ± 3 | 0.54 ± .03 | 0.77 ± .09 | <0.03 | | | | |
| 85-2013 | 3 | Jul. 11 85 | 6.529 | 9 ± 2 | 0.08 ± .02 | 1.18 ± .07 | <0.02 | | | | |
| 85-2014 | 4 | Jul. 8 85 | 4.540 | 55 ± 3 | 0.67 ± .04 | 2.00 ± .12 | <0.04 | | | | |
| 85-2015 | 5 | Jul. 25 85 | 3.511 | 6 ± 2 | 0.06 ± .03 | 2.94 ± .17 | <0.02 | | | | |

Table 14 (Cont'd). Radionuclide results for air monitoring stations identified by location numbers shown in Figure 21 for 1985 and 1986 (F, air filter, C, filter cartridge)

| Sample | Stn # | Sample Date | ABS HUM | H-3 (Bq/l) | H-3 (Bq/m³) | Be-7 (mBq/m³) F | Cs-137 (mBq/m³) F | Cs-134 (mBq/m³) F | Ru-103 (mBq/m³) F | I-131 (mBq/m³) F | I-131 (mBq/m³) C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 85-2016 | Air 1 | Aug. 14 85 | 5.174 | 7 ± 2 | 0.08 ± .03 | 3.67 ± .15 | <0.03 | | | | |
| 85-2017 | 1 | Jul. 22 85 | 5.127 | 73 ± 3 | 0.86 ± .04 | 1.67 ± .19 | <0.04 | | | | |
| 85-2018 | 2 | Aug. 8 85 | 4.833 | 8 ± 2 | 0.09 ± .03 | 1.45 ± .19 | <0.04 | | | | |
| 85-1019 | 3 | Jul. 30 85 | 4.194 | 9 ± 2 | 0.09 ± .02 | 4.00 ± .43 | <0.08 | | | | |
| 85-2020 | 4 | Aug. 20 85 | 6.316 | 5 ± 4 | 0.05 ± .02 | 2.33 ± .24 | <0.05 | | | | |
| 85-2021 | 5 | Sep. 14 85 | 4.887 | 9 ± 2 | 0.07 ± .02 | -- | -- | | | | |
| 85-2022 | 1 | Aug. 18 85 | 6.508 | 52 ± 3 | 0.59 ± .02 | 1.38 ± .16 | <0.04 | | | | |
| 85-2023 | 2 | Sep. 17 85 | 4.931 | 28 ± 3 | 0.29 ± .02 | 2.75 ± .14 | <0.03 | | | | |
| 85-2024 | 3 | Sep. 11 85 | 4.044 | 7 ± 2 | 0.06 ± .02 | 4.61 ± .26 | <0.06 | | | | |
| 85-2025 | 4 | Sep. 12 85 | 3.061 | 4 ± 2 | 0.04 ± .02 | 1.83 ± .09 | <0.03 | | | | |
| 85-2026 | 1 | Oct. 10 85 | 2.760 | 3 ± 2 | 0.02 ± .02 | 3.03 ± .10 | <0.02 | | | | |
| 85-2027 | 2 | Sep. 13 85 | 4.594 | 33 ± 3 | 0.26 ± .02 | 1.51 ± .13 | <0.03 | | | | |
| 85-2028 | 3 | Oct. 17 85 | 3.876 | 3 ± 2 | 0.02 ± .02 | 1.51 ± .09 | <0.02 | | | | |
| 85-2029 | 4 | Oct. 2 86 | 4.795 | 18 ± 3 | 0.19 ± .03 | 8.56 ± .30 | <0.05 | | | | |
| 85-2030 | 5 | Oct. 6 86 | 3.760 | 3 ± 2 | 0.03 ± .02 | 3.52 ± .16 | <0.03 | | | | |
| 85-2031 | 1 | Nov. 7 85 | 2.314 | 5 ± 2 | 0.03 ± .03 | 2.32 ± .10 | <0.02 | | | | |
| 85-2032 | 2 | Oct. 5 86 | 4.841 | 41 ± 2 | 0.04 ± .02 | 0.48 ± .09 | <0.03 | | | | |
| 85-2033 | 3 | Nov. 14 85 | 2.716 | 36 ± 2 | 0.10 ± .02 | 1.17 ± .09 | <0.02 | | | | |
| 85-2034 | 4 | Nov. 17 85 | 1.843 | 46 ± 2 | 0.084 ± .001 | 1.00 ± .13 | <0.04 | | | | |
| 85-2035 | 5 | Oct. 23 86 | 2.295 | 4 ± 2 | 0.02 ± .01 | 2.49 ± .13 | <0.03 | | | | |
| 85-2036 | 1 | Dec. 10 85 | 1.792 | 8 ± 3 | 0.02 ± .01 | 3.93 ± .15 | <0.03 | | | | |
| 85-2037 | 2 | Nov. 26 85 | 2.459 | 7 ± 2 | 0.14 ± .01 | 1.41 ± .11 | <0.03 | | | | |
| 85-2038 | 3 | Dec. 26 85 | 1.073 | 145 ± 3 | 0.326 ± .006 | 2.25 ± .12 | <0.03 | | | | |
| 85-2039 | 4 | Dec. 29 85 | 0.940 | 39 ± 2 | 0.112 ± .006 | 1.77 ± .15 | <0.04 | | | | |
| 85-2040 | 5 | Nov. 10 85 | 2.256 | -- | -- | 1.94 ± .13 | <0.03 | | | | |
| 85-2041 | 1 | Jan. 12 86 | 1.346 | 21 ± 3 | 0.044 ± .006 | 1.93 ± .09 | <0.02 | | | | |
| 85-2042 | 2 | Nov. 19 85 | 3.180 | 6 ± 2 | 0.02 ± .01 | 0.44 ± .10 | <0.03 | | | | |
| 85-2047 | 2 | Dec. 13 85 | 1.021 | 14 ± 2 | 0.036 ± .005 | 0.64 ± .11 | <0.03 | | | | |
| 85-2050 | 5 | Dec. 28 85 | 0.999 | 3 ± 2 | 0.008 ± .005 | 2.21 ± .13 | <0.03 | | | | |

Table 14 (Cont'd). Radionuclide results for air monitoring stations identified by location numbers shown in Figure 21 for 1985 and 1986 (F, air filter, C, filter cartridge)

| Sample | Stn. # | Sample Date | ABS HUM | H-3 (Bq/l) | H-3 (Bq/m³) | Be-7 (mBq/m³) F | Cs-137 (mBq/m³) F | Cs-134 (mBq/m³) F | Ru-103 (mBq/m³) F | I-131 (mBq/m³) F | I-131 (mBq/m³) C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | Air | Monitoring | Sta | Data | | | | | | | |
| 86-2041 | 1 | Jan. 12 86 | 1.346 | 20 ± 2 | 0.044 ± .006 | 1.93 ± .09 | <0.02 | | | | |
| 86-2511 | 1 | Feb. 10 86 | 1.460 | 15 ± 2 | 0.034 ± .006 | 4.19 ± .22 | <0.05 | | | | |
| 86-2512 | 2 | Jan. 31 86 | 1.038 | 28 ± 2 | 0.054 ± .006 | 0.69 ± .12 | <0.04 | | | | |
| 86-2513 | 3 | Feb. 5 86 | 0.743 | 124 ± 3 | 0.249 ± .007 | 2.90 ± .30 | <0.03 | | | <0.16 | |
| 86-2514 | 4 | Feb. 14 86 | 0.915 | 27 ± 2 | 0.059 ± .004 | 3.40 ± .29 | <0.07 | | | <0.43 | |
| 86-2515 | 5 | Jan. 30 86 | 0.0901 | 7 ± 3 | 0.016 ± .007 | 3.14 ± .18 | <0.05 | | | <0.14 | |
| 86-2516 | 1 | Mar. 17 86 | 1.330 | 10 ± 2 | 0.04 ± .01 | 4.88 ± .22 | <0.03 | | | <0.10 | |
| 86-2517 | 2 | Feb. 21 86 | 1.0165 | 14 ± 2 | 0.050 ± .008 | 0.36 ± .09 | <0.04 | | | <0.22 | |
| 86-2518 | 3 | Mar. 26 86 | 2.122 | 52 ± 3 | 0.23 ± .01 | 2.81 ± .12 | <0.02 | | | <0.08 | |
| 86-2519 | 4 | Mar. 16 86 | 1.164 | 17 ± 2 | 0.08 ± .01 | 3.57 ± .26 | <0.05 | | | <0.13 | |
| 86-2520 | 5 | Mar. 11 86 | 0.877 | 6 ± 3 | 0.05 ± .02 | 2.30 ± .13 | <0.04 | | | <0.20 | |
| 86-2521 | 1 | Apr. 20 86 | 1.855 | 12 ± 2 | 0.07 ± .02 | 3.91 ± .13 | <0.02 | | | <0.10 | |
| 86-2522 | 2 | Mar. 14 86 | 1.128 | 46 ± 3 | 0.17 ± .01 | 1.18 ± .27 | <0.05 | | | | |
| 86-2523 | 3 | Apr. 23 86 | 1.608 | 394 ± 5 | 3.32 ± .04 | 1.43 ± .13 | <0.03 | | | <0.11 | |
| 86-2524 | 4 | Apr. 19 86 | 1.763 | 56 ± 3 | 0.33 ± .02 | 4.24 ± .51 | <0.10 | | | <0.16 | |
| 86-2525 | 5 | Mar. 21 86 | 0.802 | 4 ± 3 | 0.013 ± .009 | 3.60 ± .19 | <0.03 | | | <0.14 | |
| 86-2526 | 1 | May 18 86 | 1.610 | 15 ± 2 | 0.12 ± .02 | 2.82 ± .35 | 1.86 ± .05 | 0.85 ± .36 | 0.98 ± .04 | 0.51 ± .05 | 1.35 ± .13 |
| 86-2527 | 2 | Apr. 12 86 | 1.301 | 45 ± 3 | 0.26 ± .02 | <0.29 | <0.04 | | | | <0.04 |
| 86-2528 | 3 | May 20 86 | 1.280 | 358 ± 5 | 3.18 ± .05 | 1.39 ± .15 | 1.04 ± .04 | 0.44 ± .03 | 0.54 ± .04 | 0.21 ± .04 | 1.59 ± .11 |
| 86-2529 | 4 | May 14 86 | 2.123 | 28 ± 3 | 0.24 ± .03 | 5.22 ± .38 | 3.49 ± .09 | 1.57 ± .06 | 1.69 ± .06 | 1.05 ± .08 | 6.77 ± .24 |
| 86-2530 | 5 | Apr. 16 86 | 0.699 | 3 ± 3 | 0.02 ± .02 | 1.85 ± .08 | <0.02 | | | | <0.06 |
| 86-2531 | 1 | Jun. 10 86 | 2.634 | 3 ± 3 | 0.03 ± .03 | 4.55 ± .26 | 0.44 ± .03 | 0.11 ± .02 | 0.2 ± .03 | <0.12 | <0.06 |
| 86-2532 | 2 | May 2 86 | 2.274 | 75 ± 3 | 0.79 ± .04 | <0.38 | <0.04 | | | | <0.16 |
| 86-2533 | 3 | Jun. 18 86 | 1.599 | 47 ± 3 | 0.43 ± .03 | 2.79 ± .16 | 0.05 ± .01 | <0.03 | 0.10 ± .02 | <0.09 | <0.16 |
| 86-2534 | 4 | Jun. 21 86 | 1.314 | 40 ± 3 | 0.35 ± .03 | 11.53 ± .42 | 0.20 ± .04 | <0.07 | 0.39 ± .04 | <0.12 | <0.12 |
| Chernobyl | Survey | Under | Way | | | | | | | | |
| 86-2536 | 1 | Jul. 8 86 | 1.481 | 4 ± 3 | 0.04 ± .03 | 3.12 ± .22 | <0.05 | | | | |
| 86-2537 | 2 | Aug. 9 86 | 2.554 | 36 ± 3 | 0.46 ± .04 | 2.12 ± .22 | <0.04 | | | | <0.15 |

Table 14 (Cont'd). Radionuclide results for air monitoring stations identified by location numbers shown in Figure 21 for 1985 and 1986 (F, air filter; C, filter cartridge)

| Sample | Stn. # | Sample Date | ABS HUM | H-3 (Bq/l) | H-3 (Bq/$m^3$) | Be-7 (mBq/$m^3$) F | Cs-137 (mBq/$m^3$) F | Cs-134 (mBq/$m^3$) F | Ru-103 (mBq/$m^3$) F | I-131 (mBq/$m^3$) F | I-131 (mBq/$m^3$) C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 86-2538 | 3 | Jul 31 86 | 1.770 | 18 ± 2 | 0.21 ± .03 | 1.08 ± .15 | <0.03 | | | | <0.15 |
| 86-2539 | 4 | Jul 14 86 | 2.440 | 27 ± 2 | 0.33 ± .04 | 2.67 ± .39 | <0.06 | | | | <0.15 |
| 86-2540 | 5 | Aug. 12 86 | 2.002 | <3 | <0.0060 | 2.07 ± .21 | <0.04 | | | | |
| 86-2981 | 1 | Aug. 18 86 | 3.175 | <4 | <0.0122 | 5.02 ± .47 | <0.07 | | | | <0.13 |
| 86-2982 | 2 | Sep. 25 86 | 2.331 | 73 ± 3 | 0.56 ± .02 | 1.38 ± .17 | <0.04 | | | | <0.11 |
| 86-2983 | 3 | Oct. 2 86 | 1.568 | 13 ± 2 | 0.10 ± .02 | 1.14 ± .10 | <0.02 | | | | <0.14 |
| 86-2984 | 4 | Sep. 13 86 | 2.411 | 11 ± 3 | 0.10 ± .03 | 10.3 ± 3.9 | <0.06 | | | | <0.11 |
| 86-2985 | 5 | Sep. 25 86 | 1.872 | 3 ± 2 | 0.02 ± .02 | 1.24 ± .15 | <0.03 | | | | <0.13 |
| 86-2986 | 1 | Sep. 27 86 | 2.459 | 6 ± 3 | 0.05 ± .092 | 3.10 ± .18 | <0.04 | | | | <0.12 |
| 86-2987 | 2 | Oct. 24 86 | 0.806 | 49 ± 3 | 0.30 ± .02 | 3.56 ± .28 | <0.05 | | | | <0.08 |
| 86-2988 | 3 | Oct. 30 86 | 1.372 | 64 ± 3 | 0.34 ± .02 | 2.6 ± .13 | <0.03 | | | | <0.24 |
| 86-2989 | 4 | Oct. 3 86 | | | | 2.31 ± .19 | <0.04 | | | | <0.09 |
| 86-2990 | 5 | Oct. 25 86 | 1.196 | 3 ± 3 | 0.02 ± .01 | 2.33 ± .29 | <0.05 | | | | <0.04 |
| 86-2991 | 1 | Oct. 18 86 | 1.388 | 8 ± 3 | 0.04 ± .02 | 2.41 ± .17 | <0.03 | | | | <0.10 |
| 86-2992 | 2 | Nov 15 86 | 0.763 | 58 ± 3 | 0.20 ± .01 | 2.76 ± .02 | <0.04 | | | | <0.12 |
| 86-2993 | 3 | Dec. 7 86 | 0.930 | 129 ± 3 | 0.41 ± .01 | 2.16 ± .09 | <0.01 | | | | <0.12 |
| 86-2994 | 4 | Oct. 29 86 | 1.050 | 12 ± 2 | 0.07 ± .02 | 3.34 ± .18 | <0.03 | | | | <0.09 |
| 86-2995 | 5 | Nov 21 86 | 0.871 | <4 | <0.003 | 2.89 ± .26 | <0.05 | | | | <0.11 |
| 86-2996 | 1 | Nov. 10 86 | 1.228 | 6 ± 3 | 0.02 ± .01 | 1.14 ± .13 | <0.03 | | | | <0.13 |
| 86-2997 | 2 | Dec. 6 86 | 1.057 | 33 ± 3 | 0.029 ± .003 | 3.46 ± .23 | <0.04 | | | | |
| 86-2999 | 4 | Nov. 24 86 | 0.739 | 9 ± 3 | 0.04 ± .01 | 2.81 ± .17 | <0.03 | | | | <0.13 |
| 86-3000 | 5 | Dec. 18 86 | 0.724 | <3 | <.002 | 2.97 ± .23 | <0.03 | | | | |
| 86-2765 | 1 | Dec. 4 86 | 0.697 | 6 ± 3 | 0.03 ± .01 | 2.22 ± .10 | <0.02 | | | | <0.06 |

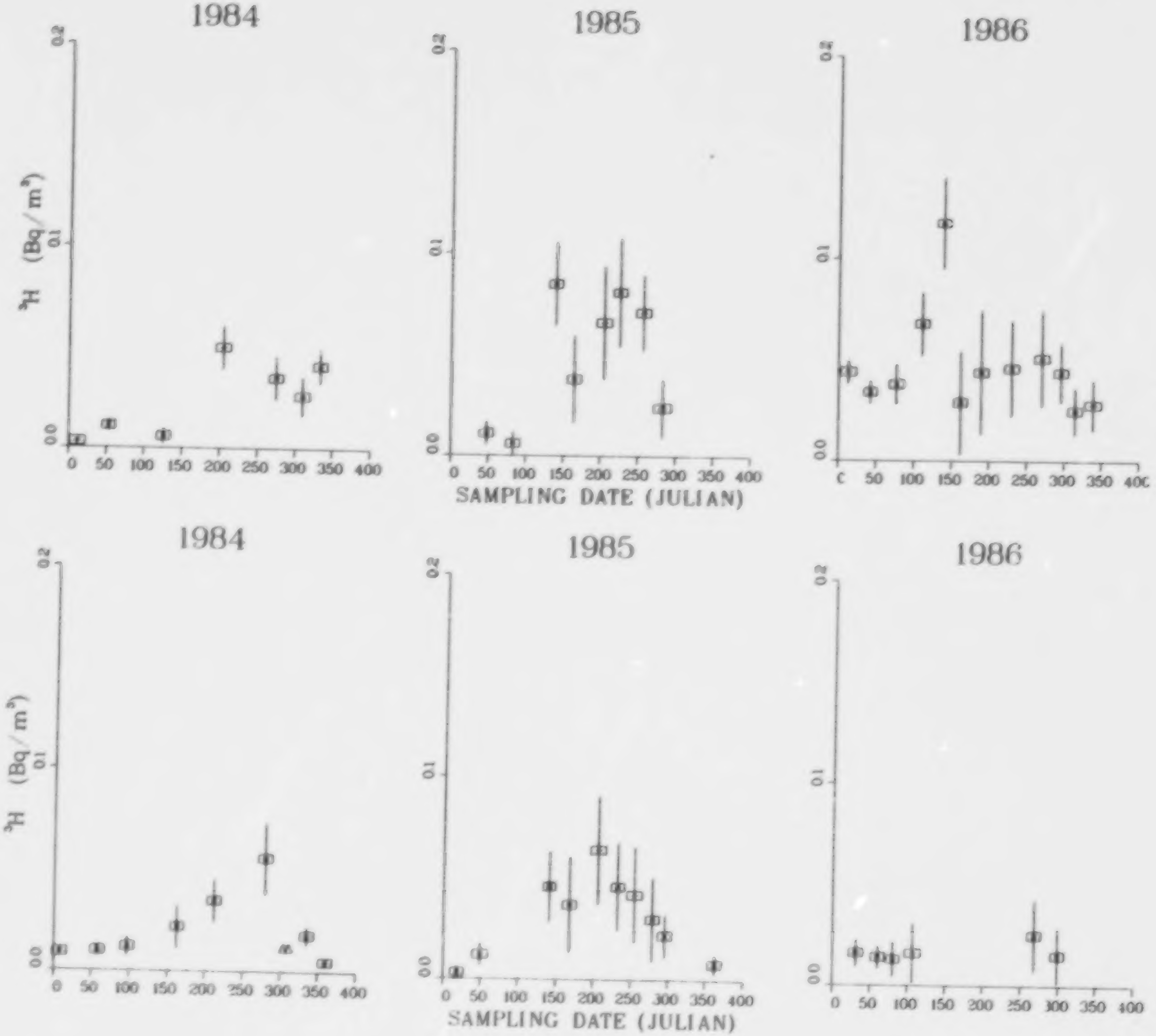


Figure 26. Tritium activity (Bq/m$^3$) as a function of sampling date for air monitoring stations 1 (upper) and 5 (lower) for 1984, 1985 and 1986.

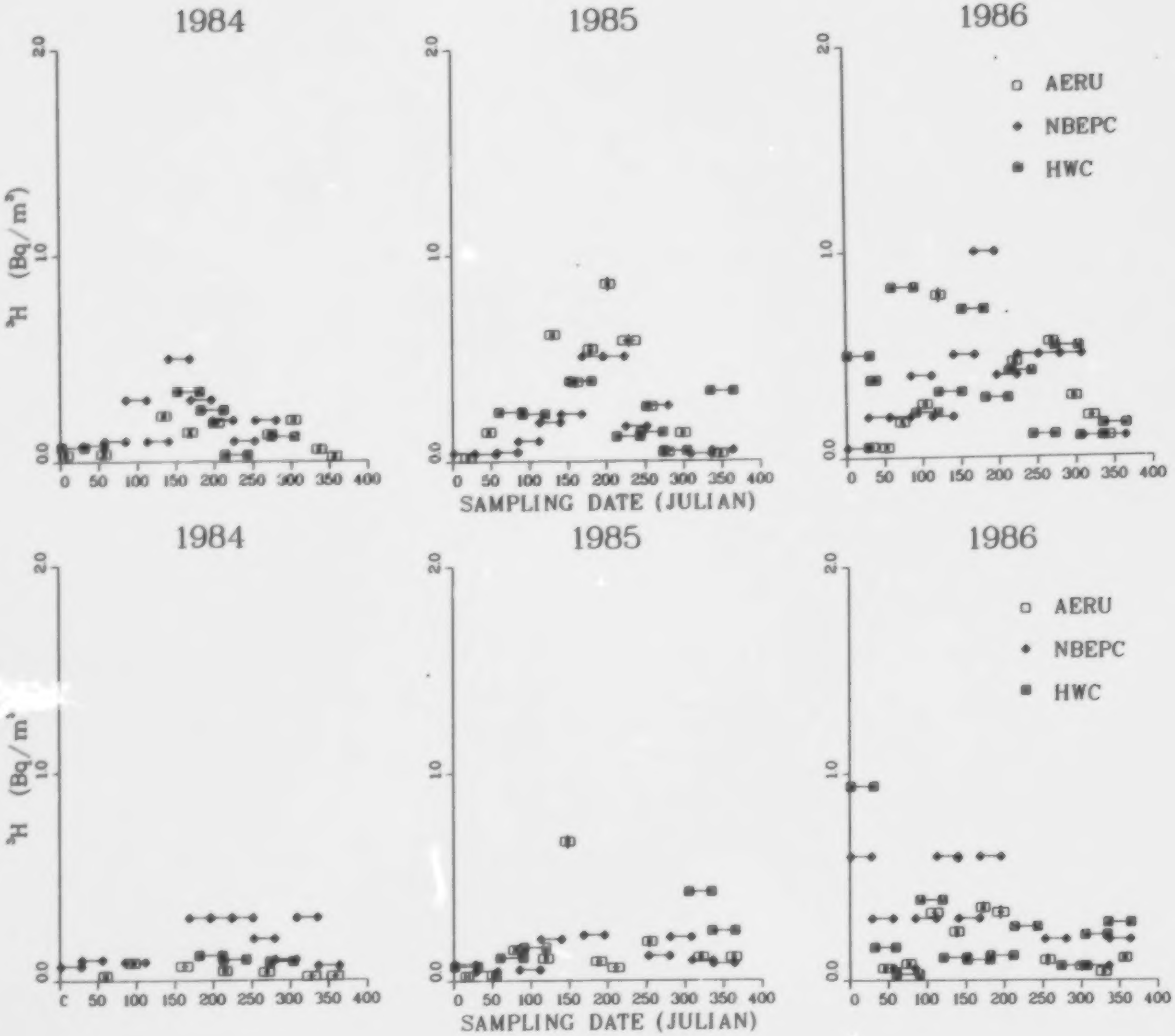


Figure 27. Tritium activity (Bq/m³) as a function of sampling date for air monitoring stations 2 (upper) and 4 (lower) for 1984, 1985 and 1986. Comparisons are included for NBEPC and HWC tritium activities for samples collected from stations at the same locations.

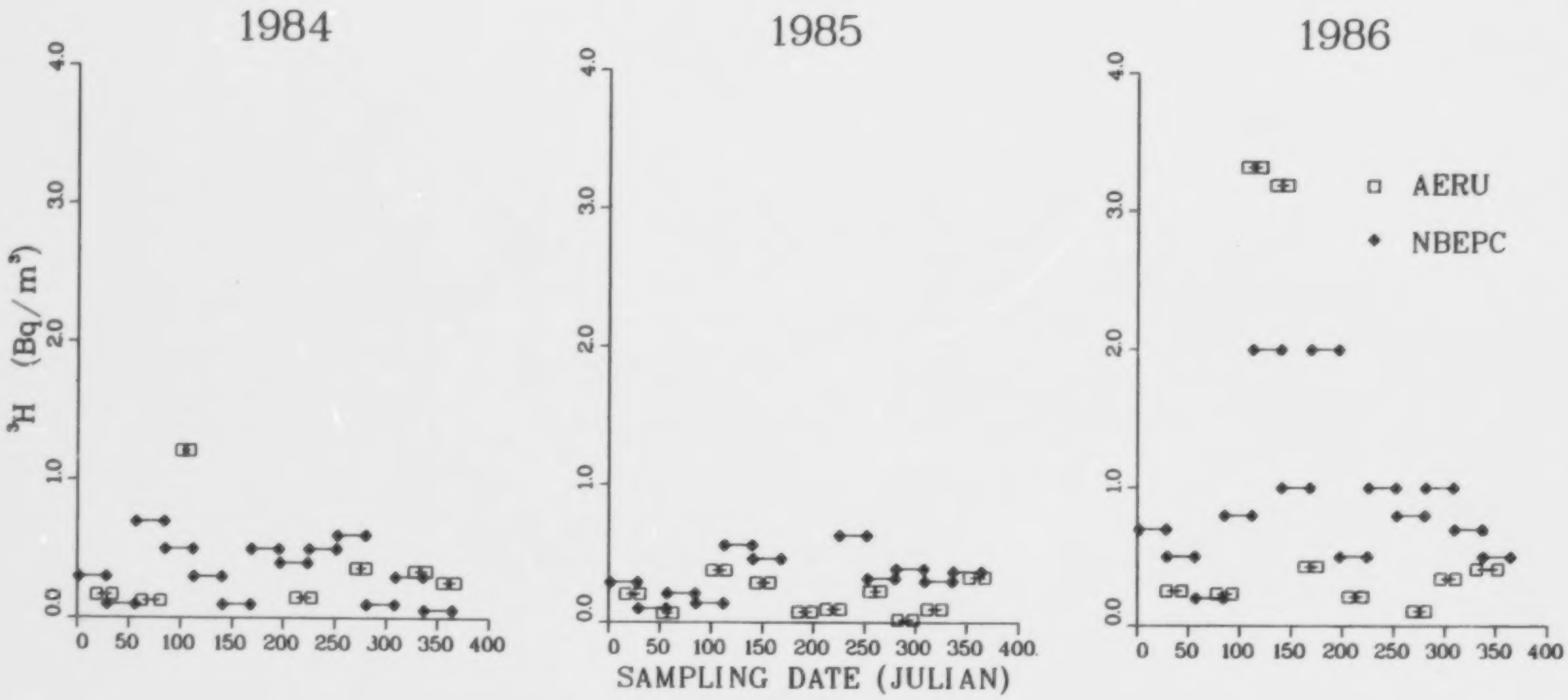


Figure 28. Tritium activity (Bq/m$^3$) as a function of sampling date for air monitoring station 3 for 1984, 1985 and 1986. Comparison with NBEPC tritium activities are included.

of the increase in relative humidity and Figures 26-28 depict "real" increases in tritium activity observed during 1985 and 1986.

Figures 27 and 28 show the comparison of tritium activities measured by NBEPC and HWC from stations operated at the same sites. In general the three sets of data agree within experimental error but in several cases there is considerable scatter in the data set, possibly as a result of longer sampling periods (4 weeks) by NBEPC and HWC.

The Point Lepreau NGS has been shown to be the source of elevated tritium levels in the Point Lepreau area (Nelson *et al.*, 1985, 1986). Because the dispersion of airborne contaminants is mainly dependent on the meteorological conditions prevalent during the time of release, it should be possible to relate tritium activities observed at the individual air monitoring stations to wind conditions in the Point Lepreau area. Figure 29 illustrates the relationship between wind direction and tritium activity in air by quarter year for 1985/86 for those air monitoring stations located in the Point Lepreau area.

In the first quarter (January - March), the winds were more frequently from the north through the west for both 1985 and 1986 (Figure 29). As expected, this results in higher tritium activities at air monitoring Stations 2 and 3. In 1986, there was a more pronounced component from the south which may explain the higher tritium activity at AMS #1.

During the second quarter the prevailing wind direction shifts to the southwest leading to clearly enhanced tritium levels at AMS #2 in Dipper Harbour. The high signal observed at AMS #3 in 1986 was probably a source function effect related to the higher amount of tritium released to the atmosphere during that period.

The results of the third quarter also illustrate the dominance of a southwesterly wind direction (Nelson *et al.*, 1985). The wind rose suggests that the higher tritium signals should be observed at AMS #2 and lower tritium levels at AMS #4 which is in general agreement with experimental results. The wind frequency in the direction of AMS #3 is low and the signal observed at this station is correspondingly low.

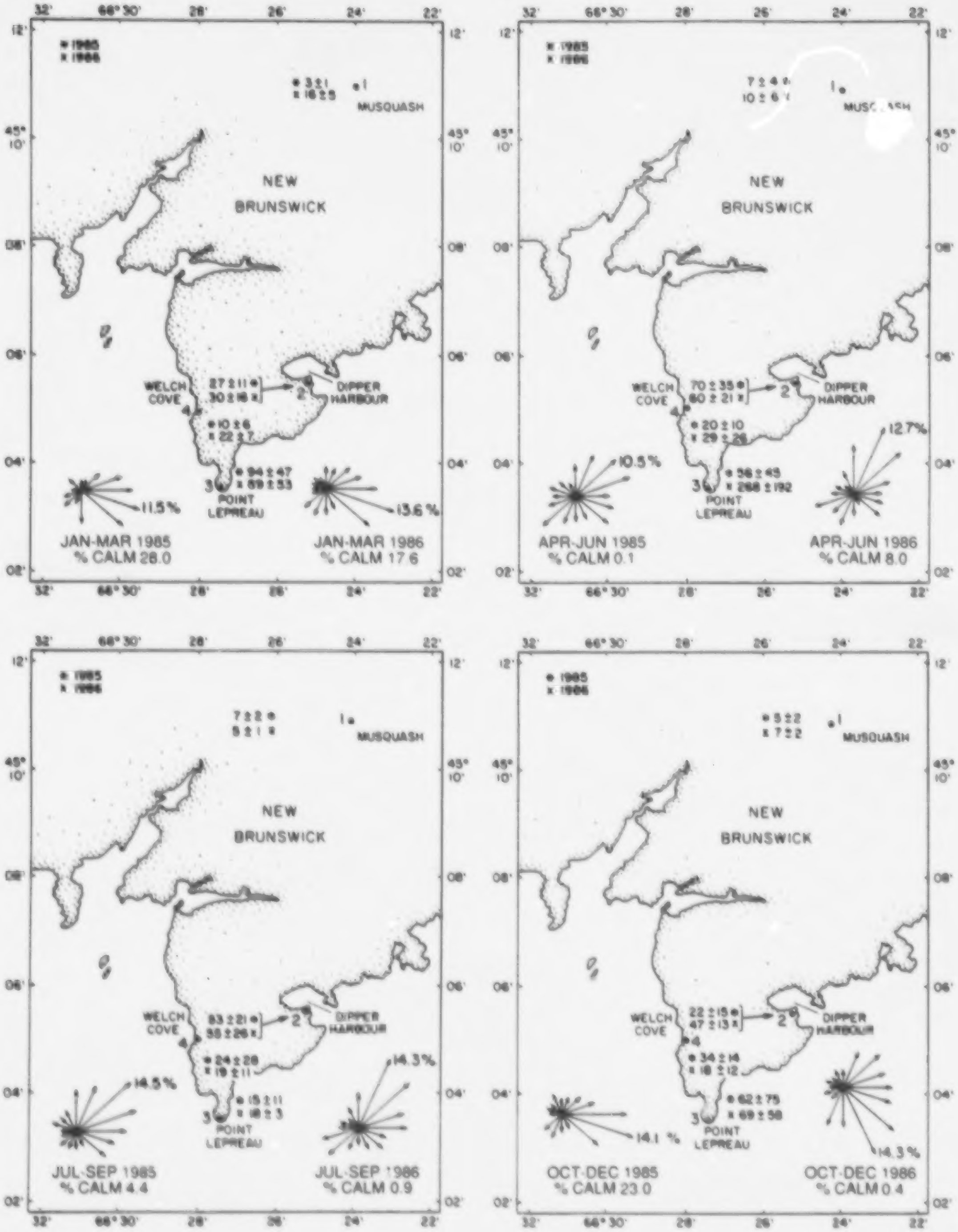

32'
66° 30'
28'
26'
24'
22'
12'
45° 10'
08'
06'
04'
02'
● 1985
× 1986
● 3 ± 1
× 16 ± 5
1
MUSQUASH
NEW BRUNSWICK
WELCH COVE
27 ± 11 ●
30 ± 16 ×
2
DIPPER HARBOUR
4
● 10 ± 6
× 22 ± 7
● 94 ± 47
× 69 ± 53
3
POINT LEPREAU
11.5%
13.6 %
JAN-MAR 1985
% CALM 28.0
JAN-MAR 1986
% CALM 17.6
7 ± 4 ●
10 ± 6 ×
70 ± 35 ●
60 ± 21 ×
● 20 ± 10
× 29 ± 26
● 36 ± 43
× 268 ± 192
10.5%
12.7%
APR-JUN 1985
% CALM 0.1
APR-JUN 1986
% CALM 8.0
7 ± 2 ●
5 ± 1 ×
83 ± 21 ●
55 ± 26 ×
● 24 ± 28
× 19 ± 11
● 15 ± 11
× 18 ± 3
14.5%
14.3%
JUL-SEP 1985
% CALM 4.4
JUL-SEP 1986
% CALM 0.9
● 5 ± 2
× 7 ± 2
22 ± 15 ●
47 ± 13 ×
● 34 ± 14
× 18 ± 12
● 62 ± 75
× 69 ± 58
14.1 %
14.3 %
OCT-DEC 1985
% CALM 23.0
OCT-DEC 1986
% CALM 0.4

**Figure 29.** Relationship between atmospheric tritium distribution (Bq/l) and wind direction for 1985 and 1986. Results are shown by quarter.

The fourth quarter results show a difference in the wind distribution patterns for 1985 and 1986. The 1986 wind rose indicated a higher component of wind frequency from the southwest and, as a result, the tritium activity at AMS#2 was higher in 1986 compared to 1985. As the wind direction shifted back to the northwest higher tritium signals were observed at AMS #3 in both 1985 and 1986.

In general, the tritium activity in atmospheric water vapour near the NGS continues to increase with increasing releases of tritium as gaseous effluent. The two factors that control the distribution of tritium in the vicinity of the NGS are the total activity of tritium released and the directional frequency of the winds in the area.

### 3.2.2 Radionuclides in Atmospheric Particulates

Air filters containing airborne particulate matter were analyzed for gamma-emitting radionuclides by direct counting of samples on hyper-pure Ge detectors. The results for 1985 and 1986 are presented in Table 14 for stations located as shown in Figure 21. The effects of the Chernobyl nuclear accident were evident from the results of air filter analysis in 1986 and will be discussed in Chapter 7. Be-7 was the only radionuclide detected on a routine basis during 1985 and 1986.

#### 3.2.2.1 Beryllium-7

Be-7 is a naturally occurring radionuclide which is the product of the cosmic ray fragmentation of atmospheric nitrogen and oxygen that takes place in the upper stratosphere. Be-7, because of its high specific activity, short half-life (53 days), lack of dilution by stable beryllium, and its particle affinity, has been used extensively to estimate the residence time of aerosols in the upper troposphere. Furthermore, because of its particle reactive characteristics, Be-7 is useful as a particle tracer for rapid process in the marine and aquatic environments (Krishnaswami *et al.* 1980).

The Be-7 results from 1985 and 1986 are presented in Table 14 and Figure 30. The range of Be-7 values measured in 1985 was 0.3 ± 0.1 to 8.5 ± 0.3 mBq/$m^3$ and the average Be-7 activity for all stations was 2.4 ± 1.4 mBq/$m^3$. The range of Be-7 activities measured for 1986 was 0.4 ± 0.1 to 11.5 ± 0.4 mBq/$m^3$ and the average for all stations was 3.0 ± 2.0 mBq/$m^3$. These values represent an increase over 1984 values of 1.7 mBq/$m^3$ but are within the range of Be-7 activities measured during the course of the monitoring program (1.6 mBq/$m^3$ to 3.1 mBq/$m^3$). Be-7 activities measured by NBEPC during 1985 and 1986 were 2.8 and 2.6 mBq/$m^3$ respectively and also show an increase over Be-7 activities measured in 1984 (Sutherland, 1986, 1987).

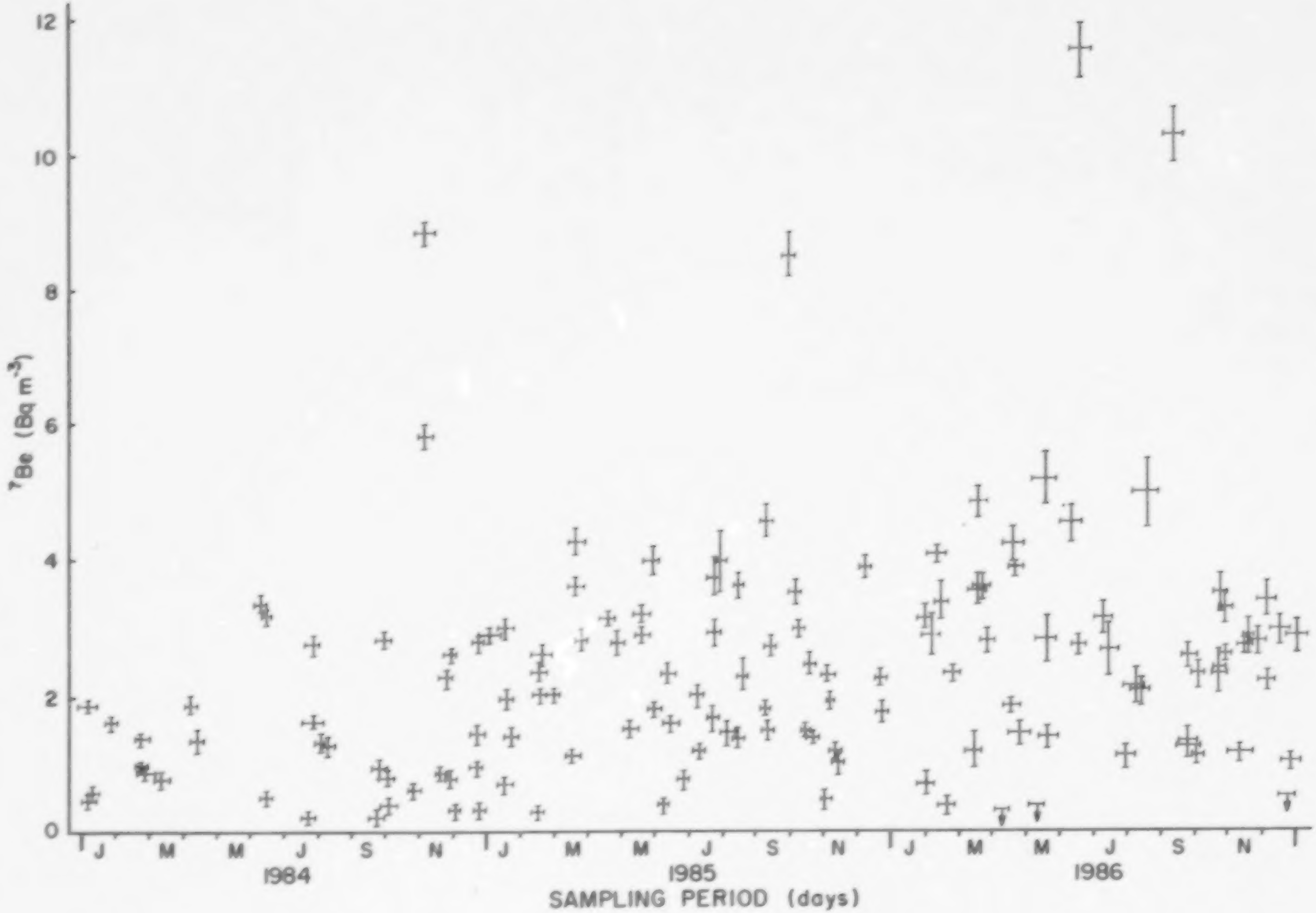


Figure 30. Be-7 activity measured in air particulate material collected at air monitoring stations 1 to 5 for 1984, 1985 and 1986.

## 4.0 THE MARINE ENVIRONMENT

The dispersion of radionuclides released into coastal waters depends upon the physical characteristics of the receiving water mass and on the chemical properties of the element. Phenomena such as currents, turbulent diffusion, isotopic dilution and biological transport act to dilute and disperse radionuclides. Currents and mixing processes are more intense in the coastal zone, where major ocean circulation patterns, winds and tidal motions combine and follow the general trend of the coastline resulting in flows tangential to it. Simultaneously, chemical and physical forces such as absorption, ion exchange, flocculation, sedimentation and the passage of radionuclides through the food chain act as concentrating mechanisms (Rice *et al.* 1974).

The shallow depths of the coastal region restrict the quantities of water available for the dilution of land discharged pollutants. The physical boundary of the shoreline also limits the directions in which dispersion can occur. The nearshore zone is influenced by river runoff, high SPM, intertidal areas, the contrasting nature of shorelines, which can range from bedrock to extensive mud flats, tidal cycles, seasonal variability of physical and biological phenomena and the occurrence of man made constructions and contaminant discharges (IAEA, 1985).

The release of radioactivity into the marine environment from a nuclear generating station is effectively a point source input that can lead to relatively high activities in localized areas. In general, the overall extent of the contamination is limited and increases above background are rarely measurable at distances greater than a few hundred kilometers from the point of discharge.

### 4.1 Radionuclide Concentration Processes

Marine organisms can accumulate and redistribute radionuclides independently of other physio-chemical processes resulting in the potential "concentration" of radioactivity through different levels of the food chain. Several concepts have been utilized to describe these processes. Two of the most useful are the concentration factor (CF) and the biological half-life.

The term concentration factor has been used to describe the biological uptake of a chemical species and is defined as the activity of a nuclide B per unit fresh weight of an organism divided by the activity per unit volume of water (Coughtrey *et al.* 1983),

$$CF = (100 - \%H_2O)\, A_B\ sample / A_B\ water \tag{2}$$

where % $H_2O$ is the percent water per sample wet weight, $A_B$ *sample* is the activity of B in the sample dry weight, and $A_B$ *water* is the activity of B in sea water. CF's provide a qualitative description of radionuclide uptake but tend to be of limited value for higher trophic levels where organisms tend to utilize a variety of food sources, or for infaunal organisms which ingest large amounts of sediment.

The term biological half life is defined as the time required for an organism to exchange half of its total inventory of an element. The concept is important in watermasses where radionuclide concentrations vary as a function of time, i.e. releases from nuclear installations. Higher trophic levels tend to have longer biological half lives and may never attain a steady state radionuclide concentration. In contrast primary producers such as plankton often have turn over rates on the order of hours and effectively mirror changing environmental levels.

## 4.2 Sampling, Sample Processing and Analysis

An assessment of environmental effects associated with the biological uptake of radioactivity requires a surveillance program consistent with local and regional marine energetics, the nature of the food web, water circulation and zones of productivity. The original sampling program employed for the Point Lepreau NGS was designed with these considerations in mind. Based on the results from both the pre-operational (Bishop *et al.* 1980, Smith *et al.* 1981-1982 and Ellis *et al.* 1984) and the operational (Nelson *et al.* 1985-1986) phase, the sampling program was modified at the start of the 1985 sampling year.

Sampling sites were chosen as shown in Figure 31 and marine sites were restricted to areas at the cooling water intake (Indian Cove) and at the outfall (Duck Cove) where initial effects of releases from the NGS would be observed. In addition, samples of lobster were collected at Digby, N.S. to assess movement of radionuclides across the Bay of Fundy. Species selected for the monitoring program are shown in Table 15 and were considered to be representative of the major marine habitats in the area, as well as, known accumulators of radionuclides and commercially important species. Species were chosen to represent all trophic levels and trends in radionuclide transport so that accumulation should become apparent at some level within the sampling assemblage. Samples are collected once a year for AERU by the N.B. Department of the Environment, as well as by AERU staff on an opportunity basis.

The processing of biological samples has been described previously (Ellis *et al.* 1984). The tritium content of marine biological samples, terrestrial samples, and soils was determined using an azeotropic distillation method (Mogissi *et al.* 1973). Freeze dried, homogenized samples were analyzed for gamma-emitting radionuclides using two 25% efficient hyperpure germanian detectors. A gamma spectrum for each sample was automatically analyzed using a Digital Micro PDP 11 computer running Canberra Spectran-F software which identified and quantified radionuclide peaks of interest. Samples were analyzed using one of five standard counting geometries, corresponding to sample volumes of 500, 300, 100, 50 and 20 mℓs. Detection limits (Bq/kg) for each radionuclide of interest are given in Appendices 3 and 4 for the five counting geometries. A more detailed discussion of AERU counting procedures is given in Ellis *et al.* (1984). Table 16 contains concentration factors and AERU detection limits for radionuclides of interest and the various marine groups sampled for PLEMP.

## 4.3 Marine Algae

The use of marine algae as bio-indicators for radionuclides in the marine environment is well documented. The NKA (Nordic Liason Committee for Atomic Energy)

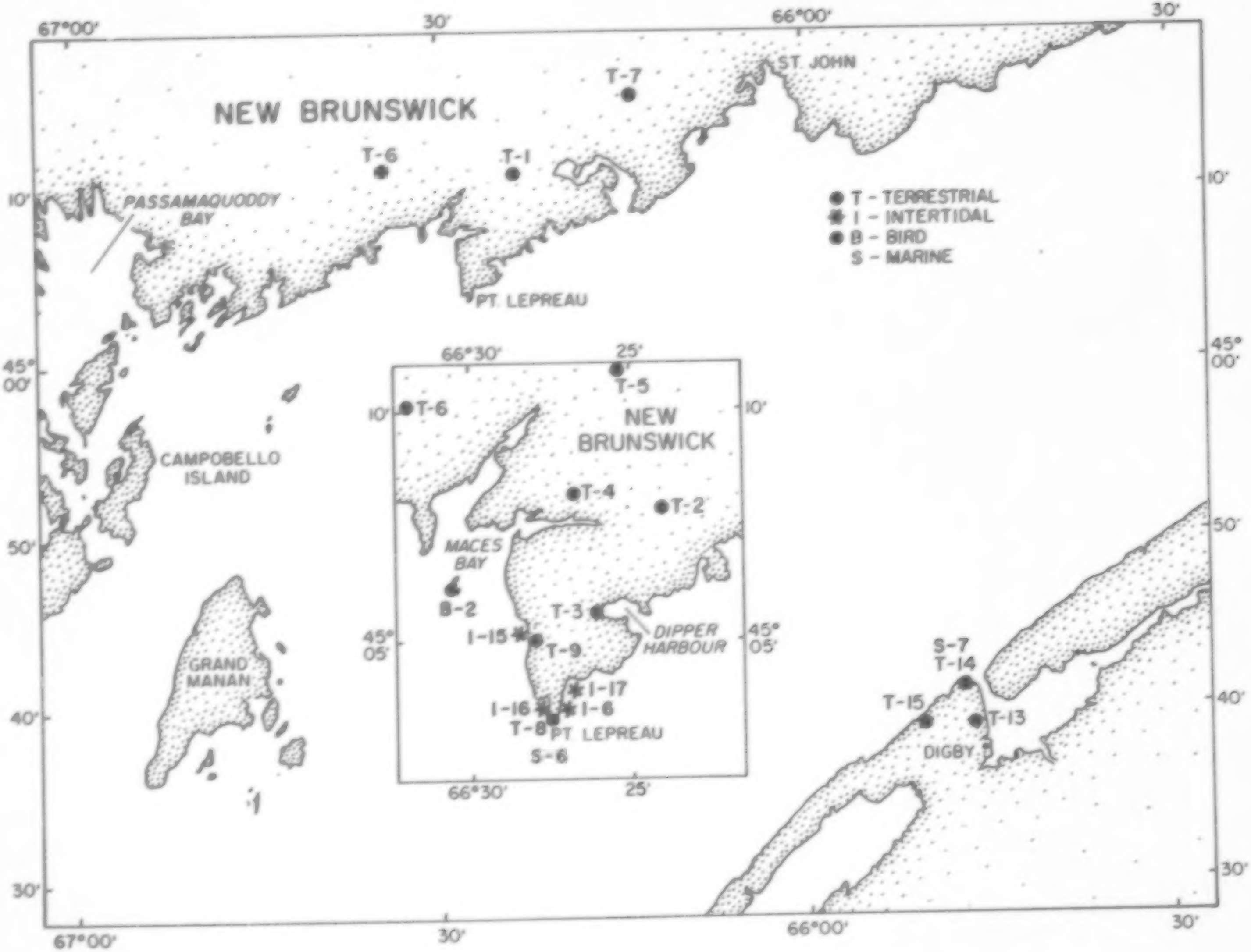

67°00'
30'
66°00'
30'
NEW BRUNSWICK
T-7
ST. JOHN
T-6
T-1
PASSAMAQUODDY BAY
PT. LEPREAU
● T - TERRESTRIAL
✱ I - INTERTIDAL
● B - BIRD
S - MARINE
CAMPOBELLO ISLAND
GRAND MANAN
66°30'
25'
T-5
T-6
NEW BRUNSWICK
T-4
T-2
MACES BAY
B-2
T-3
DIPPER HARBOUR
I-15
T-9
I-17
I-16
I-6
T-8
PT LEPREAU
S-6
S-7
T-14
T-15
T-13
DIGBY
10'
45° 00'
50'
45° 05'
40'
30'

Figure 31. PLEMP sampling sites chosen for 1985 and 1986.

Table 15. Representative species for different marine sampling regimes near Point Lepreau.

| Species | Embayment, Estuary | Intertidal Zone | Subtidal Zone | Pelagic Zone |
|---|---|---|---|---|
| Plants |  | Rockweed, Irish moss, dulse, Fucus | Laminaria |  |
| Grazers |  | Periwinkle | Sea urchin |  |
| Detritus Feeders |  | Gammarus |  |  |
| Suspension Feeders | Soft shelled clams | Blue Mussel | Horse Mussel, Scallop |  |
| Predators and Scavengers | Sandshrimp | Green Crab, Hermit Crab | Rock Crab, Lobster | Rock Crab |
| Fish |  | Flounder |  | Herring |
| Birds | Purple sandpiper | Eider Duck | Cormorant, Herring Gull |  |
| Mammals |  |  | Harbour Seal |  |
| Planktonic Forms |  |  |  | Bulk Samples Phyto- and Zooplankton |

Table 16. Concentration factors and AERU detection limits for radionuclides of interest and various marine groups.

| Radionuclide | Half Life (Days, Years) | Plankton | Macro-Algae | Crustaceans | Molluscs | Surface Water Fish | AERU Detection Limit (mBq/kg) |
|---|---|---|---|---|---|---|---|
| | | Concentration* Factor | Concentration* Factor | Concentration* Factor | Concentration* Factor | Concentration* Factor | |
| Ce-141 | 33.00 d | 9x10$^{4}$ | 5x10$^{3}$ | 1x10$^{3}$ | 5x10$^{3}$ | 5x10$^{3}$ | 170 |
| Ce-144 | 284.40 d | 9x10$^{4}$ | 5x10$^{3}$ | 1x10$^{3}$ | 5x10$^{3}$ | [illegible] | 460 |
| Co-58 | 71.20 d | 5x10$^{3}$ | 1x10$^{4}$ | 5x10$^{3}$ | 5x10$^{4}$ | 1x10$^{4}$ | 77 |
| Co-60 | 5.27 y | 5x10$^{3}$ | 1x10$^{4}$ | 5x10$^{3}$ | 5x10$^{4}$ | 1x10$^{4}$ | 65 |
| Cr-51 | 27.70 d | 2x10$^{3}$ | 2x10$^{3}$ | 5x10$^{2}$ | 8x10$^{3}$ | 2x10$^{3}$ | 1,100 |
| Cs-137 | 30.00 y | 2x10$^{1}$ | 2x10$^{1}$ | 3x10$^{1}$ | 3x10$^{1}$ | 2x10$^{1}$ | 62 |
| I-131 | 8.10 d | 1x10$^{3}$ | 1x10$^{3}$ | 1x10$^{1}$ | 1x10$^{3}$ | 1x10$^{3}$ | 780 |
| Mn-54 | 321.60 d | 6x10$^{3}$ | 6x10$^{3}$ | 1x10$^{4}$ | 5x10$^{3}$ | 4x10$^{3}$ | 67 |
| Nb-95 | 35.20 d | 1x10$^{3}$ | 3x10$^{3}$ | 2x10$^{2}$ | 1x10$^{3}$ | 3x10$^{3}$ | 110 |
| Ru-103 | 39.40 d | 2x10$^{5}$ | 2x10$^{3}$ | 1x10$^{2}$ | 2x10$^{3}$ | 2x10$^{3}$ | 93 |
| Ru-106 | 368.00 d | 2x105 | 2x10$^{3}$ | 1x10$^{2}$ | 2x10$^{3}$ | 2x10$^{3}$ | 540 |
| Zn-65 | 244.10 d | 3x104 | 2x10$^{1}$ | 5x10$^{4}$ | 3x10$^{1}$ | 1x10$^{1}$ | 140 |
| Zr-95 | 65.00 d | 6x10$^{4}$ | 3x10$^{3}$ | 2x10$^{32}$ | 5x10$^{3}$ | 2x10$^{3}$ | 150 |

* IAEA, 1985

** Based on sample in Geometry 3, counting time of 10$^{5}$ sec. one month subsequent to sample collection.

bio-indicator study identified the algae *Fucus vesiculosus* as being available in all parts of the North Atlantic region. For several of the radionuclides studied this species showed accumulation factors on the order of 100 and higher. Other useful algae mentioned include *Ascophyllum noddsum*, *Fucus serratus*, and *Laminaria* sp. (Aarkrog *et al.* 1985). Guimares *et al.* (1985) found that fast uptake, high bio-accumulation factors (ranging from 50 to 50,000) and long biological half lives make algae important monitors for radionuclide releases.

The marine algae species selected for monitoring in 1985/86 and the results of the analysis are presented in Table 17. Cesium-137 was detected in one sample of Irish moss in 1985, but no radionuclides were detected in any other algae samples collected that year. The results for 1986 show that Cs-137 was detected in all but one sample. Cesium-137 levels ranged from <0.45 to 3±1 Bq/kg for all samples. Cs-134 was detected in one sample of laminaria at an activity of 2±1 Bq/kg. The increase in Cs-137 activity in 1986 is within experimental error of pre-operational levels.

## 4.4 Marine Animals

Marine animal samples collected for PLEMP fall into three categories - molluscs, crustacea and vertebrates. Marine molluscs, concentrate radionuclides directly from seawater, by ingestion of contaminated food and by ingestion of contaminated sediment. Marine crustacea, such as crabs and lobsters, form an important part of the decomposition cycle in marine habitats with many representatives in the decomposer fauna. In general marine vertebrates are less suitable as indicator species because of their mobility and inefficient accumulation of radionuclides compared to other organisms. But, because of their position in the food web, in relation to man, and their commercial importance, several species of marine vertebrates are sampled on an opportunity basis.

Marine molluscs sampled during 1985/86 at sites located as shown in Figure 31 include scallops (*Pecten maximus*), blue mussel (*Mytilus modiolus*), horse mussel (*Modiolus modiolus*), periwinkles (*Littorina littorea*) and the soft shelled clam (*Mya arenaria*). The results for marine molluscs are presented in Table 18. Cesium-137 was the only radionuclide that was detected in any of the samples collected and the activities observed were within pre-operational levels.

Marine crustacea samples collected from sites shown in Figure 31 include lobster (*Homarus americanus*), sea urchin (*Strongylocentrotus droebachiensis*) and gammarus (*Gammaras oceanicus*). Cesium-137 was detected in a sea urchin sample at a level equivalent to those measured in pre-operational marine crustacea samples.

## 4.5 Tritium in Marine Organisms

Tritium is released from nuclear reactors both as molecular tritium gas via stack gas discharges and as tritiated water (HTO). Molecular tritium is converted into HTO by either exchange or oxidative reactions. The HTO interacts with living organisms in two ways firstly through exposure of organisms to contaminated water and secondly, through the ingestion by organisms of contaminated food. Tritium incorporated by marine and aquatic organisms can exist as tissue-free water and tissue-bound water (i.e. incorporated into organic molecules). Incorporation is dependent on the physico-chemical state of the tritium in the liquid effluent. Tritiated water, HTO, is exchanged with free tissue water very quickly and can represent up to 95% of the tritium in the organism (IAEA, 1981).

In general, tritium freely exchanges with hydrogen and the bio-concentration of tritium in organisms is negligible. However, studies, have shown levels of tritium incorporated into organic matter at activities 20 times higher than those observed in the surrounding water (IAEA, 1981). These seemingly anomalous results were due to the presence of tritiated organic compounds in the effluent that were readily absorbed and only slowly equilibrated with environmental tritium levels.

Tritium activities found in marine samples collected at sites shown in Figure 31 are presented in Table 19. Samples collected in August, 1986 in Duck Cove show elevated levels of tritium (245, 283 Bq/ℓ) in both marine algae and molluscs. These cannot be due to a

Table17. Radionuclide results for marine algae samples collected near Point Lepreau.

| Sample Type | Collection Date | Sample No. | Component | Sample | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Site | Wt(g) | Geom # | % $H_2O$ | Cs-137 Bq/kg | Cs-134 Bq/kg |
| Ascophylum | 1980-82 | -- | Whole | 1-4,6,8 | -- | -- | -- | 0.4 ± 0.1 | |
| Fucus | 1980-82 | -- | Whole | 1-6 | -- | -- | -- | 0.3 ± 0.1 to<br>0.5 ± 0.4 | |
| Laminaria | 1980-82 | -- | Whole | 1-2,3,6,9 | -- | -- | -- | 0.3 ± 0.1<br>0.9 ± 0.5<br>0.5 ± 0.3 to<br>1.2 ± 0.7 | |
| Ascophylum | 4 July 85 | 85-2208 | Whole | 1-6 | 98.12 | 2 | 75 | < 1 | |
| Ascophylum | " | 85-2209 | Whole | 1-6 | 65.43 | 2 | 76 | < 1 | |
| Ascophylum | " | 85-2212 | Whole | 1-6 | 62.16 | 2 | 69 | < 1 | |
| Irish Moss | 4 Jul 85 | 85-2213 | Whole | 1-6 | 48.18 | 2 | 77 | 2 ± 1 | |
| Irish Moss | " | 85-2214 | Whole | 1-6 | 45.02 | 2 | 78 | < 2 | |
| Fucus | 4 Jul 85 | 85-2215 | Whole | 1-6 | 118.00 | 2 | 86 | < 1 | |
| Ascophylum | 14 Aug 86 | 86-13465 | Whole | DC | 173.91 | 1 | 68 | 0.8 ± 0.2 | |
| Ascophylum | " | 86-13474 | Whole | DC | 114.38 | 1 | 68 | 1.4 ± 0.3 | |
| Ascophylum | " | 86-13452 | Whole | IC | 108.70 | 2 | 69 | 0.8 ± 0.3 | < 1 |
| Ascophylum | " | 86-13462 | Whole | IC | 13.31 | 2 | 70 | < 0.4 | |
| Chondrus | 14 Aug 86 | 86-13453 | Whole | DC | 72.60 | 2 | 73 | 0.5 ± 0.4 | < 1 |
| Chondrus | " | 86-13454 | Whole | DC | 81.78 | 2 | 77 | 0.6 ± 0.3 | < 1 |
| Chondrus | " | 86-13460 | Whole | DC | 97.79 | 2 | 74 | 0.7 ± 0.3 | < 1 |
| Chondrus | " | 86-13463 | Whole | IC | 64.79 | 2 | 73 | 1.0 ± 0.4 | < 1 |
| Fucus | 14 Aug 86 | 86-13456 | Whole | DC | 106.05 | 2 | 83 | 1.3 ± 0.4 | < 1 |
| Fucus | " | 86-13466 | Whole | DC | 89.93 | 2 | 78 | 0.5 ± 0.3 | |
| Fucus | " | 86-13457 | Whole | IC | 52.15 | 2 | 58 | 1.0 ± 0.5 | |
| Fucus | " | 86-13467 | Whole | IC | 81.07 | 2 | 72 | 1.3 ± 0.4 | < 1 |
| Laminaria | 14 Aug 86 | 86-13470 | Whole | DC | 76.28 | 2 | 80 | 0.6 ± 0.4 | < 1.3 |
| Laminaria | " | 86-13476 | Whole | DC | 48.72 | 2 | 82 | 1.0 ± 0.6 | 2.2 ± 0.8 |
| Laminaria | " | 86-13455 | Whole | IC | 52.62 | 2 | 58 | 3 ± 1 | |
| Laminaria | " | 86-13458 | Whole | IC | 59.62 | 2 | 79 | 0.8 ± 0.7 | < 2 |

Table18. Radionuclide results for marine animal samples collected near Point Lepreau.

| Sample Type | Collection Date | Sample No. | Component | Sample | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Site | Wt(g) | Geom # | % $H_2O$ | Cs-137 Bq/kg | Cs-134 Bq/kg |
| Littorina | 1980-82 | -- | Flesh | I-6 | -- | -- | -- | <3 | |
| | | | Shell | I-6 | -- | -- | -- | <0.2 | |
| Modiolus | 1980-82 | -- | Flesh | I-8,6 | -- | -- | -- | 1.7±1.2 | |
| | " | | Shell | I-8,6 | -- | -- | -- | <1 to 1.7±1.2 | |
| | | | | | | | | 0.1±0.1 | |
| Crab | 1980-82 | | Flesh | I-6, I-8 | -- | -- | -- | | |
| | | | Shell | | -- | -- | -- | <6 | |
| Lobster | 4 Jul 85 | 85-2089 | Hepatopancreas | I-6 | 98.51 | 3 | 59 | <3 | |
| Lobster | " | 85-2098 | Hepatopancreas | I-7 | 48.91 | 3 | 53 | <2 | |
| Lobster | " | 85-2493 | Hepatopancreas | I-10 | | | 53 | <1 | |
| Littorina | 4 Jul 85 | 85-2211 | Whole | I-1 | 337.14 | 1 | 23 | | |
| Littorina | 14 Aug 86 | 12473 | Flesh | DC | 16.24 | 4 | | 0.4±0.2 | |
| Littorina | " | 12473 | Shell | DC | 559.71 | 1 | 23 | <2 | <3 |
| Littorina | " | 13472 | Flesh | IC | 20.19 | 3 | | <0.1 | <0.1 |
| Littorina | " | 13472 | Shell | IC | 470.51 | 1 | 26 | 0.8±0.8 | <3 |
| Modiolus | 4 Jul 85 | 85-2210 | Whole | I-1 | 388.34 | 1 | 45 | 0.2±.1 | <0.2 |
| Mussels | 15 Aug 86 | 12704 | Whole | IC | 144.46 | 2 | 48 | <0.2 | |
| Mytilus | 14 Aug 86 | 86-13459 | Whole | IC | 222.45 | 1 | 61 | 0.8±0.2 | |
| Mytilus | " | 86-13475 | Whole | IC | 275.58 | 1 | 61 | <0.4 | |
| Crab | 14 Aug 85 | 86-13464 | Whole | DC | 91.25 | 2 | 67 | 0.3±0.1 | |
| Crab | " | 13471 | Whole | IC | 104.78 | 2 | 74 | <1 | |
| Gammarus | 14 Aug 85 | 86-13715 | Whole | S-6 | 52.32 | 2 | 73 | <1 | <1 |
| Clam | 15 Aug 86 | 13707 | Flesh | IC | 9.81 | 4 | 90 | <2 | |
| Clam | " | 13703 | Flesh | IC | 262.77 | 2 | 90 | <4 | |
| Sea Urchin | 15 Aug 86 | 13706 | Whole | IC | 226.25 | 1 | 64 | 0.5±.2 | 0.3±0.2 |
| Scallop | 15 Aug 86 | 13701 | Gut | IC | 253.30 | 1 | 81 | 0.4±0.2 | |
| Scallop | " | 13702 | Shell | DC | 679.88 | 1 | 1 | 0.6±0.1 | |
| Scallop | " | 13705 | Flesh | DC | 62.67 | 2 | 79 | 1.0±0.4 | <0.1 |
| Ass't Benthic | 11 Dec 85 | 85-2858-1 | Worm, tube, clam | Pt. Lepreau | 15.14 | 4 | 58 | 0.8±0.3 | |
| Sea Cucumber | 11 Dec 85 | 85-2858-2 | Whole | Pt. Lepreau | 50.28 | 2 | 86 | 1±1 | |
| Star Fish | 11 Dec 85 | 85-2858-3 | Whole | Pt. Lepreau | 9.43 | 4 | 66 | 3±1 | <2 |
| Clams | 11 Dec 85 | 85-2858-4 | Whole | Pt. Lepreau | 137.60 | 2 | 40 | 4±2 | <1 |
| | | | | | | | | 3±1 | <1 |

Table 19. Tritium levels found in marine systems.

| Sample | Collection Date | Sample No. | Component | Site | H-3 (Bq/ℓ) |
|---|---|---|---|---|---|
| Ascophyllum | Feb. 26/86 | 13410 | Whole | I-6 | 5±3 |
| Ascophyllum | Feb. 26/86 | 13414 | Whole | I-6 | 5±3 |
| Ascophyllum | Feb. 26/86 | 13415 | Whole | I-6 | 4±3 |
| Ascophyllum | Feb. 26/86 | 13439 | Whole | I-17 | 6±3 |
| Ascophyllum | Feb. 26/86 | 13430 | Whole | I-15 | <4 |
| Ascophyllum | Aug. 14/86 | 13462 | Whole | I-16 | 2±3 |
| Ascophyllum | Aug. 14/86 | 13465 | Whole | I-17 | 245±5 |
| Fucus | Feb. 26/86 | 13416 | Whole | I-6 | 4±3 |
| Fucus | Feb. 26/86 | 13440 | Whole | I-17 | 4±3 |
| Fucus | Feb. 26/86 | 13411 | Whole | I-6 | 3±3 |
| Fucus | Feb. 26/86 | 13413 | Whole | I-6 | 3±3 |
| Fucus | Feb. 26/86 | 13431 | Whole | I-15 | <3 |
| Fucus | Aug. 14/86 | 13456 | Whole | I-17 | 283±5 |
| Fucus | Aug. 14/86 | 13457 | Whole | I-16 | <4 |
| Laminaria | Feb. 26/86 | 13412 | Whole | I-6 | 5±3 |
| Laminaria | Aug. 14/86 | 13470 | Whole | I-17 | 31±3 |
| Laminaria | Aug. 14/86 | 13455 | Whole | I-16 | 15±3 |
| Chondrus | Aug. 14/86 | 13463 | Whole | I-16 | 9±3 |
| Mya Arenaria | Aug. 15/86 | 13708 | Shell | I-16 | 16±3 |
| Mya Arenaria | Aug. 15/86 | 13707 | Flesh | I-16 | 25±3 |
| Pecten Maxim | Aug. 15/86 | 13701 | Gut | I-17 | <3 |
| Pecten Maxim | Aug. 15/86 | 14702 | Shell | I-17 | 18±3 |
| Pecten Maxim | Aug. 15/86 | 13705 | Flesh | I-17 | 23±3 |
| Modiolus Modiolus | Aug. 14/86 | 13709 | Shell | I-17 | 16±3 |
| Modiolus Modiolus | Aug. 14/86 | 13710 | Flesh | I-17 | 4±3 |
| Littorina Littorea | Aug. 14/86 | 13711 | Flesh | I-17 | 128±4 |
| Littorina Littorea | Aug. 14/86 | 13712 | Shell | I-17 | 127±4 |

concentration effect because concentration factors for most organisms for tritium are close to unity. The collection period of samples in August corresponds to a monthly release of tritium of 24 TBq/ℓ (Table 1) which is equivalent to a mean outfall tritium activity of 350 Bq/ℓ in seawater (using the monthly data from the LEM multiplied by the DEL and divided by the monthly cooling water outflow). These high tritium activities in organisms probably represent a transient response to tidal cycle and effluent release conditions that resulted in outflow water moving into Duck Cove before significant dilution of the tritium plume could take place. Current vectors from previous thermal plume studies have indicated that under low and falling tidal conditions water from the cooling water outfall is transported into Duck Cove (Nelson *et al*. 1986).

## 5.0 AQUATIC AND TERRESTRIAL ENVIRONMENTAL PHASES

The complex interrelationship between the terrestrial and aquatic environmental phases is schematically illustrated in Figure 32. Radionuclides can enter the system via the atmosphere, or from effluent releases into the cooling water cycle. In both cases, molecular and turbulent diffusion processes act immediately to reduce radionuclide activity as a function of distance from the source. Concurrently, phenomena such as gravitational settling, precipitation scavenging, impaction, chemical absorption, and exchange act to concentrate radionuclides. The high particle reactivity of some radionuclides leads to their rapid removal from the air water continuum and plays an important role in their subsequent availability for biological uptake.

Ultimately, radionuclides tend to accumulate in "sinks" composed of the deeper strata of soils, sediments and their associated deposits of organic detritus where they are tightly bound and have negligible contact with biological components. The rates at which radionuclides are distributed throughout an ecosystem determine the speed with which their steady state distribution is reached and the final distribution patterns that are obtained.

The operational monitoring program for the Point Lepreau NGS emphasizes the early detection and monitoring of reactor derived radionuclides while continuing to stress an ecosystem approach to the understanding of radionuclide transport. The monitoring program was altered at the start of 1985 using the first two years of operational monitoring data as a guideline. Sampling was restricted to sites closer to the NGS where effects of the operation of the plant would be detected first. The locations of the sampling sites are illustrated in Figure 31, and include sites in Digby, N.S. which serve both as background sites and to assess the transport of radionuclides across the Bay of Fundy.

### 5.1 Aquatic Systems

The factors that govern the distribution of radionuclides in aquatic systems include viscosity, temperature, light, periodic mixing, redox conditions and pH, and sedimentation

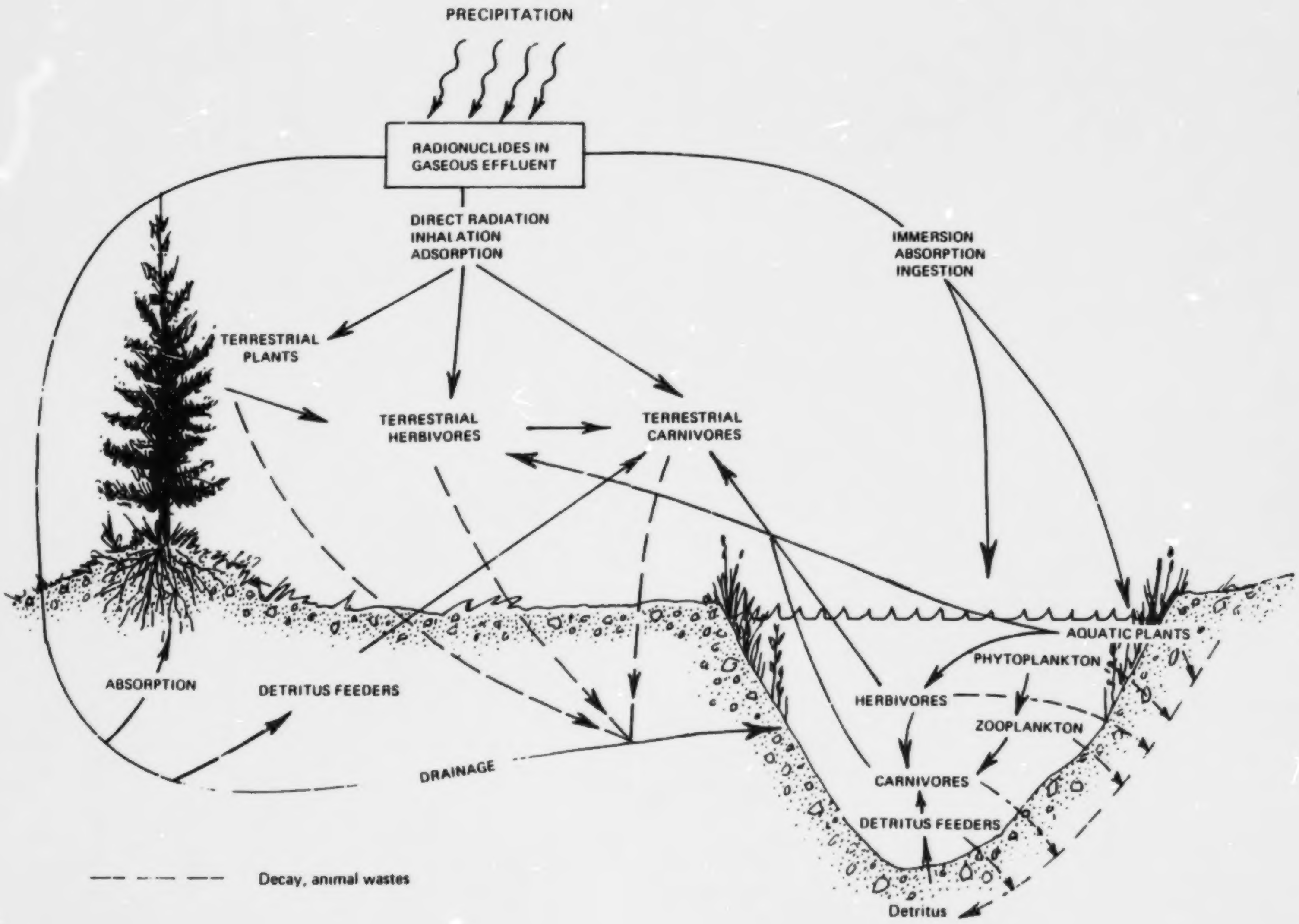

PRECIPITATION
RADIONUCLIDES IN GASEOUS EFFLUENT
DIRECT RADIATION
INHALATION
ADSORPTION
IMMERSION
ABSORPTION
INGESTION
TERRESTRIAL PLANTS
TERRESTRIAL HERBIVORES
TERRESTRIAL CARNIVORES
AQUATIC PLANTS
PHYTOPLANKTON
HERBIVORES
ZOOPLANKTON
CARNIVORES
DETRITUS FEEDERS
Detritus
ABSORPTION
DETRITUS FEEDERS
DRAINAGE
Decay, animal wastes

Figure 32. Illustration of transport pathways for radionuclides in aquatic and terrestrial environments.

rates. These factors affect the distribution and activity of aquatic organisms as well as the translocation of radioactivity though the water body. The major differences exhibited in the distribution of radionuclides in aquatic and marine systems are the result of chemical and physical differences between seawater and freshwater. As an example, river water on average contains 120 ppm total dissolved solids but this value is highly variable in comparison to seawater which contains about 35,000 ppm total dissolved solids. Consequently similar organisms in freshwater or seawater can be expected to accumulate retain and excrete minerals in a different fashion due to their ionic condition in relation to the surrounding medium.

The five sampling sites, T-1 to T-5, selected for collecting aquatic samples are located as illustrated in Figure 31. Two of the sites (T-2 and T-4) are small lakes and the remaining sites are stream locations. Added to this in the 85/86 season are stream sites at T-8 and T-9 as illustrated in Figure 31 at the tip of Point Lepreau. The methodology for the preparation of biological, sediment and water samples and for subsequent analysis using nuclear instrumentation are similar to procedures discussed earlier in this report (Section 4.2). The principal difference is that the analytical problems associated with the high salt content of marine samples are not encountered in freshwater samples.

### 5.1.1 Water Column Results

Freshwater samples were collected during two field trips in 1986. In February, 20 ℓ water samples were collected by AERU at sites located as shown in Figure 31. In July 1985, the New Brunswick Department of Municipal Affairs and Environment collected 20 mℓ samples of freshwater for tritium analysis at site locations shown in Figure 31. The results for both sets of samples are presented in Table 20. Results for samples collected in February 1986 are included in Chapter 6 (Leak Survey).

Tritium results for the samples ranged from 4 ± 3 Bq/ℓ to 34 ± 3 Bq/ℓ (avg: 18 ± 11) with the highest activities found at those sites located closest to the NGS. The average

Table 20. Cs-137 and H-3 results for water and suspended particulate material from aquatic sites near Point Lepreau.

| Sample No. | Sampling Site | SPM Level mg/ℓ | H-3 Bq/ℓ | Cs-137 Soluble (mBq/ℓ) | Cs-137 Particulate | | Total Cs-137 mBq/ℓ | Distibution Coeff. kd (Bq/g/Bq/ml) |
|---|---|---|---|---|---|---|---|---|
| | | | | | (mBq/ℓ) | (Bq/g) | | |
| Pre-operational Program | T-1 | 1.00 | 8.0±2.6 | 1.0±0.7 | 0.5±0.7 | 0.5±0.7 | 1.5±2.2 | 0.5×10⁶ |
| | T-2 | 1.08 | 7.4±4.5 | 2.0±0.3 | 2.7±0.5 | 2.9±1.3 | 4.7±0.7 | 1.4×10⁶ |
| | T-3 | 0.61 | 6.1±0.1 | <0.8 | 0.4±0.6 | 0.7±1.0 | <1.2 | 0.8×10⁶ |
| | T-4 | 1.70 | 5.8±0.6 | <0.8 | 0.8±1.4 | 0.5±0.8 | <1.6 | 0.6×10⁶ |
| | T-5 | 1.04 | 4.8±0.4 | 3.3±0.5 | 1.2±1.0 | 1.3±0.9 | 4.5±3.8 | 0.3×10⁶ |
| Operational Program **1983** | | | | | | | | |
| 83-9320 | T-1 | 0.49 | 3.5±2.0 | 0.5±0.3 | 0.8±0.1 | 1.6±0.9 | 1.3±0.3 | 3.2×10⁶ |
| 83-9321 | T-2 | 0.42 | 3.5±2.0 | 0.7±0.3 | 1.4±1.1 | 3.2±2.9 | 2.1±1.1 | 4.6×10⁶ |
| 83-9323 | T-3 | 17.16 | 5.4±2.0 | 2.7±0.5 | 0.9±0.5 | 0.06±0.04 | 3.6±0.7 | 0.02×10⁶ |
| 83-9325 | T-4 | 16.56 | 2.7±2.0 | 0.5±0.5 | 1.8±1.6 | 0.11±0.10 | 2.3±1.7 | 0.22×10⁶ |
| 83-9317 | T-5 | 0.73 | 7.3±2.0 | 0.3±0.2 | 1.5±0.1 | 2.0±0.3 | 1.8±0.2 | 6.7×10⁶ |
| **1985** | | | | | | | | |
| 85-2201 | T-3 | | 18±3 | | | | | |
| 85-2202 | T-8 | | 25±3 | | | | | |
| 85-2203 | T-4 | | 4±3 | | | | | |
| 85-2204 | T-1 | | 6±3 | | | | | |
| 85-2205 | T-5 | | 14±3 | | | | | |
| 85-2206 | T-9 | | 29±3 | | | | | |
| 85-2216 | T-2 | | 16±3 | | | | | |
| 85-2217 | T-9 | | 34±3 | | | | | |
| **1986** | | | | | | | | |
| 86-13423 | T-1 | 1.37 | - | <0.1 | <2 | <1 | <6 | |
| 86-13441 | T-4 | 1.42 | - | <0.1 | <1 | <1 | <4 | |

pre-operation tritium activity measured in freshwater samples was 6.4 ± 1.3 Bq/ℓ and samples collected during 1983, the first year of the operational monitoring program, samples contained 4.5 ± 1.9 Bq/ℓ of H-3. The increase in H-3 activity observed at aquatic sampling sites reflects the increased input of H-3 from the NGS over the last three years. The results of the air monitoring survey found that even at site 1, which is located 15 kms from the plant there was an increase above background levels of H-3 in air moisture. The overall activity for H-3 in air for 1986 was 45 ± 78 Bq/ℓ and this increase is reflected in the H-3 levels found in the watershed in the Point Lepreau area.

### 5.1.2 Aquatic Plants and Animals

Aquatic plant species sampled during the 1985/86 seasons include, horsetail (*Equisetum sp.*.), wild iris (*Iris veriscolor*), bullrushes (*Typha sp.*) and water lily (*Nuphar sp.*).

Radionuclide results for samples collected at sites shown in Figure 31 are presented in Table 21. Cesium-137 activities measured in samples collected in 1985-86 are similar to levels measured both in 1984 and during the preoperational phase of PLEMP (Nelson *et al.* 1986). Samples collected in 1986 show evidence of Cs-134 derived from the Chernobyl nuclear accident and are discussed in Chapter 7.

Radionuclide results for aquatic animals collected in 1985/86 from sites shown in Figure 31 are presented in Table 22. In general, Cs-137 is concentrated rapidly by aquatic organisms and equilibrium is attained within a few days to a few weeks. Cs-137 was detected in many of the samples but at levels within the range of pre-operational measurements. Cs-137 activities in frog samples were significantly higher (avg. = 63 Bq/kg) than those found in fish samples (avg. = 14 Bq/kg). This result has been observed in previous years (Nelson *et al.* 1986) and appears to be a consequence of their respective habitats. Cs-134 was detected in one frog sample as a result of input from the Chernobyl accident.

Table 21. Radionuclide results for aquatic plant samples collected near Point Lepreau.

| Sample Type | Collection Date | Sample No. | Sample | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Site | Wt(g) | Geom # | % $H_2O$ | Cs-137(Bq/kg) | Be-7(Bq/kg) | Cs-134(Bq/kg) |
| Equisetum | 1980-82 | -- | T-1, T-5 | -- | -- | 79 | 56±80<br><2 to 2±38 | | |
| Bullrushes | 1981 | -- | T-1, T-5 | -- | -- | 88 | <13 | | |
| Iris | 1981-82 | -- | T-1, T-5 | -- | -- | 80 | 15±20<br>3±1 to 55±7 | | |
| Equisetum | 3 Jul 85 | 85-2079 | T-3 | 18.99 | 2 | 80 | 7±3 | | |
| Equisetum | " | 85-2100 | T-8 | 11.00 | 2 | 79 | <6 | | |
| Equisetum | " | 85-2486 | T-9 | 11.65 | 3 | 77 | <4 | | |
| Equisetum | 5 Jul 86 | 86-13804 | T-3 | 11.71 | 2 | 75 | 12±3 | | 7±3 |
| Equisetum | " | 86-13812 | T-5 | 12.85 | 2 | 80 | 5±2 | | |
| Equisetum | " | 86-13822 | T-8 | 18.07 | 2 | 75 | 15±3 | | |
| Equisetum | " | 86-13829 | T-9 | 19.87 | 2 | 74 | 13±2 | 437±111 | |
| Bullrushes | 3 Jul 85 | 85-2501 | | 17.42 | 2 | 85 | <4 | | |
| Bullrushes | " | 85-2080 | T-3 | 13.06 | 2 | 91 | <5 | | |
| Bullrushes | " | 85-2480 | T-8 | 22.19 | 2 | 88 | <4 | | |
| Bullrushes | " | 85-2487 | T-9 | 24.36 | 2 | 87 | <4 | | |
| Bullrushes | " | 85-2494 | T-A | 19.7 | 2 | 90 | <4 | | |
| Bullrushes | 5 Jul 86 | 86-13805 | T-3 | 35.16 | 1 | 83 | 7±1 | | <2 |
| Bullrushes | " | 86-13813 | T-3 | | | | | | |
| Bullrushes | " | 86-13823 | T-8 | 54.96 | 1 | 81 | 4±1 | | 3±1 |
| Bullrushes | " | 86-13830 | T-9 | 32.17 | 1 | 85 | 4±1 | | 3±1 |
| Bullrushes | " | 86-13846 | T-1 | 18.25 | 2 | 82 | <3 | | <4 |
| Iris | 3 Jul 85 | 85-2081 | T-3 | 17.54 | 2 | 88 | 7±2 | | |
| Iris | " | 85-2091 | T-5 | 15.08 | 2 | 84 | 50±3 | | |
| Iris | " | 85-2481 | T-8 | 10.31 | 2 | 85 | 22±4 | | |
| Iris | " | 85-2488 | T-9 | 26.81 | 1 | 86 | 4±1 | | |
| Iris | 5 Jul 86 | 86-13824 | T-8 | 31.43 | 1 | 86 | 15±1 | | 1±1 |
| Water Lily | 5 Jul 86 | 86-13817 | T-5 | 18.91 | 2 | 90 | 32±2 | | 4±2 |
| Water Lily | 3 Jul 85 | 85-2095 | T-3 | 19.48 | 2 | 91 | 45±2 | | |

Table 22. Radionuclide results for aquatic animals collected near Pt. Lepreau.

| Sample type | Date | Sample No. | Component | Sample | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Site | Wt(g) | Geom. | % $H_2O$ | Cs-137 Bq/kg | Cs-134 Bq/kg |
| Rana Sp. | 1981 | -- | Whole | T-1 to T-5 | -- | -- | 81 | 39 ± -32<br>15 ± 5 to 95 ± 20 | |
| Fish | 1981 | -- | Whole | | | | | 11 ± 8<br>5 ± 4 to 17 ± 4 | |
| Rana Sp. | Jul. 3/85 | 85-2082 | Whole | T-3 | 4.11 | 5 | 81 | 33 ± 4 | |
| Rana Sp. | Jul. 3/85 | 85-2092 | Whole | T-5 | 10.8 | 4 | 85 | 96 ± 3 | |
| Rana Sp. | Jul. 3/85 | 85-2490 | Whole | T-9 | 9.16 | 4 | 81 | 30 ± 6 | |
| Rana Sp. | Jul. 5/86 | 86-13807 | Whole | T-3 | 3.00 | 5 | 78 | 99 ± 9 | |
| Rana Sp. | Jul. 5/86 | 86-13815 | Whole | T-5 | 6.47 | 4 | 78 | 32 ± 5 | |
| Rana Sp. | Jul 5/86 | 86-13833 | Whole | T-9 | 18.37 | 3 | 76 | 89 ± 4 | 2 ± 1 |
| Fish | Ju. 3/85 | 85-2083 | Whole | T-3 | 8.16 | 4 | 78 | 16 ± 4 | |
| Fish | Jul. 3/85 | 85-2093 | Whole | T-5 | 16.16 | 4 | 80 | 12 ± 1 | |
| Insects | Jul. 3/85 | 85-2084 | Whole | T-3 | 0.74 | 5 | 67 | < 36 | |
| Insects | Jul. 3/85 | 85-2094 | Whole | T-5 | 0.58 | 5 | 69 | 35 ± 15 | |
| Insects | Jul. 3/85 | 85-2489 | Whole | T-9 | 0.43 | 5 | 66 | < 60 | |
| Insects | Jul. 3/85 | 85-2482 | Whole | T-8 | 0.34 | 5 | 85 | < 96 | |
| Insects | Jul. 5/86 | 86-13809 | Whole | T-3 | 1.00 | 5 | 75 | < 27 | |
| Insects | Jul. 5/86 | 86-13816 | Whole | T-5 | 0.74 | 5 | 75 | < 43 | |
| Insects | Jul. 5/86 | 86-13825 | Whole | T-8 | 7.18 | 3 | 70 | 7 ± 2 | |
| Insects | Jul. 5/86 | 86-13832 | Whole | T-9 | 1.91 | 5 | 66 | 25 ± 5 | |

### 5.2 Terrestrial Systems

Greater variability in radionuclide levels is generally observed in terrestrial compared to aquatic systems. The residence times of most radionuclides in air are much shorter than their residence times in water. as a result, a steady state in activity can be established through the different components Of an aquatic system more rapidly and efficiently that in a terrestrial ecosystem. Biological uptake of fallout radionuclides is generally more efficient in the terrestrial environment compared to aquatic and marine ecosystems due to the absence of a diluting medium such as water. The result is the accumulation of higher levels of fallout radionuclides in land based plants and animals as illustrated in previous PLEMP studies (Ellis *et al.* 1984, Nelson *et al.* 1985, 1986).

#### 5.2.1 Terrestrial Plants

The uptake of radionuclides by plant species depends on the degree of fallout entrapment, plant surface characteristics, age and the physiological demand for the radionuclide or stable analogue. These factors are responsible for the wide inter- and intraspecies variability in radionuclide accumulation by plants. The plant species selected for monitoring at Point Lepreau include blueberry leaves, sphagnum moss and several species of lichen including *C. Arbuscula*, *C. rangiferna* and *Usnea sp. Usnea sp.* is a species of arboreal lichen that derives all of its nutrient requirements from air moisture. In addition, samples of dogberry and spruce needles were collected on an opportunity basis and analyzed.

Radionuclide results for terrestrial plant samples collected at sites shown in Figure 31 are presented in Table 23. Cs-137 was detected in all blueberry samples with a range of 4±1 to 114±4 Bq/kg. The average Cs-137 activity was 34±27 Bq/kg in 1985 and 47±45 Bq/kg in 1986 compared to 70±65 Bq/kg in 1984 (Nelson *et al.* 1986). The Cs-137 activities measured in all terrestrial plant samples were within pre-operational levels. In addition, Cs-134 was detected in one sample collected in 1986 reflecting input from the Chernobyl accident.

Table 23. Radionuclide results for terrestrial plant samples collected in the Point Lepreau region.

| Sample Type | Collection Date | Sample No. | Component | Sample |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Site | Wt(g) | Geom # | % $H_2O$ | Cs-137(Bq/kg) | Be-7(Bq/kg) | Cs-134(Bq/kg) |
| B B Leaves | 1980-82 | -- | Leaves | T-1, T-12 | -- | -- |  | 72±64<br>14±2 to 253±7 |  |  |
| Sphagnum | 1980-82 | -- | Whole | T-1, T-5 | -- | -- |  | 203±243<br>4±4 to 930±11 |  |  |
| B B Leaves | 3 Jul 85 | 85-2502 | Leaves | T-1 | 34.37 | 1 | 66 | 4±1 |  |  |
| B B Leaves | " | 85-2097 | Leaves | T-5 | 28.44 | 2 | 63 | 46±1 |  |  |
| B B Leaves | " | 85-2484 | Leaves | T-8 | 12.12 | 3 | 3 | 66±4 |  |  |
| B B Leaves | " | 85-2492 | Leaves | T-9 | 24.10 | 2 | 66 | 22±3 |  |  |
| B B Leaves | " | 85-2085 | Leaves | T-3 | 34.06 | 1 | 65 | 27±1 |  |  |
| B B Leaves | " | 85-2489 | Leaves | T-2 | 21.65 | 1 | 70 | 10±2 |  |  |
| B B Leaves | 5 Jul 86 | 86-13835 | Leaves | T-9 | 19.81 | 2 | 63 | 114±4 |  |  |
| B B Leaves | " | 86-13837 | Leaves | T-4 | 16.88 | 2 | 61 | 7±2 |  | 6±2 |
| B B Leaves | " | 86-13840 | Leaves | T-9 | 23.49 | 2 | 58 | 42±3 |  |  |
| B B Leaves | " | 86-13843 | Leaves | T-2 | 17.5 | 2 | 61 | 6±2 |  |  |
| B B Leaves | " | 86-13847 | Leaves | T-1 | 24.03 | 2 | 59 | 64±3 | 177±61 |  |
| Sphagnum | 3 Jul 85 | 85-2078 | Whole | T-3 | 10.31 | 2 | 90 | 20±5 |  |  |
| Sphagnum | " | 85-2088 | Whole | T-5 | 2.78 | 4 | 94 | 96±8 |  |  |
| Sphagnum | " | 85-2099 | Whole | T-8 | 3.34 | 3 | 95 | 123±9 |  |  |
| Sphagnum | " | 85-2485 | Whole | T-9 | 9.5 | 2 | 90 | 7±2 |  |  |
| Sphagnum | 5 Jul 86 | 86-13811 | Whole | T-5 | 8.94 | 2 | 77 | 138±6 |  | 26±4 |
| Sphagnum | " | 86-13821 | Whole | T-8 | 6.71 | 2 | 93 | 100±6 |  | 24±6 |
| Sphagnum | " | 86-13828 | Whole | T-9 | 16.11 | 2 | 71 | 224±5 | 1062±212 | 13±3 |
| Spruce | 22 Feb 86 | 13433 | Whole | T-3 | 17.36 | 2 | 41 | 9±2 |  | <5 |
| Dog Berry | 2 Nov 86 | 13480 | Whole | T-8 | 219.65 | 1 | 74 | 5±2 | 27±7 | <1 |

## Lichen

Lichen communities have long been recognized as a reservoir of natural and artificial radionuclides. The accumulation of radionuclides in lichen is enhanced by several factors; the persistence of aerial parts (plants with persistent aerial parts contain two to ten times greater amounts of fallout material than seasonal plants, (Hanson 1967)), slow growth rate, long life span, high surface to mass ratios and foliar absorption of nutrients. These morphological and physiological characteristics of lichen, which have evolved to enable these organisms to exist in environmental extremes, serve to make them an excellent indicator of contaminant fallout. Modelling of lichen uptake at Point Lepreau (Ellis and Smith, 1987) has shown that lichen retain approximately 10-30% of fallout deposition. Their value as fallout indicators around industrial installations is well documented and there is a qualitative and quantitative improvement in lichen flora as distance increases from the source of contamination (Goyal and Seaward, 1981).

The uptake of radionuclides by lichen is influenced by several environmental factors. Habitat and latitude play a key role; lichens from pine forests contained 925 Bq/kg compared to 815 Bq/kg from tundra and 740 Bq/kg in deciduous forest (Kwapulinsky *et al.* 1985). Hanson and Eberhart (1971) found that Cs-137 content in lichen followed a seasonal cycle with maximum values in the summer and minimum in the winter. The efficiency of uptake of radionuclides by lichen follows the series Cs-137 > Sr-90 > Fe-55 > Co-60 and different species of lichen accumulate radionuclides with varying degrees of effectiveness (Kwapulinsky *et al.* 1985).

Three species of lichen were sampled in 1985/86; *Cladonia Arbuscula*, *Cladonia Rangiferna*, both ground lichen, and a species of arboreal lichen *Usnea sp.*, commonly referred to as "old man's beard" or spanish moss. Samples were collected from sites shown in Figure 31.

The results of the analysis of lichen samples collected in 1985/86 are presented in Table 24. Samples collected in 1985 were subject to a delay before analysis and only Cs-137

Table 24 Radionuclide results for whole lichen samples collected in the Point Lepreau region.

| Sample | Date | Sample No. | Sample | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Site | Wt(g) | Geom. | % $H_2O$ | Cs-137 Bq/kg | Cs-134 Bq/kg | I-131 Bq/kg | Be-7 Bq/kg | Ru-103 Bq/mg |
| C. Arbuscula | Apr. 10/85 | 85-2063 | T-1 | 13.86 | 3 | 61 | 47 ± 4 | | | | |
| C. Arbuscula | Jul. 3/85 | 85-2067 | T-3 | 13.84 | 4 | 60 | 55 ± 5 | | | | |
| C. Arbuscula | May 14/85 | 85-2367 | T-1 | 14.97 | 3 | 71 | 92 ± 3 | | | 773 ± 610 | |
| C. Arbuscula | Jul. 3/85 | 85-2500 | T-2 | 9.84 | 4 | 50 | 66 ± 4 | | | | |
| C. Arbuscula | Jul. 3/85 | 85-2506 | T-13 | 3.49 | 5 | 47 | 115 ± 7 | | | | |
| C. Arbuscula | Jul. 3/85 | 85-2508 | T-14 | 22.10 | 3 | 31 | 23 ± 2 | | | | |
| C. Arbuscula | Jul. 3/85 | 85-2510 | T-15 | 12.76 | 4 | 35 | 40 ± 3 | | | | |
| C. Arbuscula | Jul. 5/86 | 86-13820 | T-5 | 23.73 | 3 | 21 | 114 ± 3 | 17 ± 1 | < 101 | 764 ± 26 | 12 ± 2 |
| C. Arbuscula | Jul. 5/86 | 86-13839 | T-4 | 13.50 | 4 | 56 | 211 ± 5 | 13 ± 2 | < 215 | 535 ± 30 | 3 ± 3 |
| C. Arbuscula | Jul. 5/86 | 86-13842 | T-3 | 14.47 | 4 | 29 | 87 ± 2 | 11 ± 1 | < 85 | 515 ± 17 | 6 ± 2 |
| C. Arbuscula | Jul. 5/86 | 86-13845 | T-2 | 6.45 | 5 | 8 | 76 ± 3 | 3 ± 2 | < 174 | 169 ± 27 | 6 ± 3 |
| C. Arbuscula | Jul. 5/86 | 86-13849 | T-1 | 13.41 | 4 | 29 | 62 ± 1 | 8 ± 1 | < 156 | 411 ± 16 | 6 ± 2 |
| C. Arbuscula | Jul. 5/86 | 86-13851 | T-6 | 12.53 | 4 | 36 | 129 ± 4 | 13 ± 2 | < 125 | 533 ± 29 | 10 ± 3 |
| C. Rangferina | Jul. 5/86 | 86-13853 | T-7 | 14.52 | 3 | 49 | 142 ± 4 | 14 ± 2 | < 423 | 590 ± 34 | 9 ± 3 |
| Usnea Sp. | Jan. 16/85 | 85-2057 | T-1 | 17.89 | 3 | 17 | 12 ± 1 | | | | |
| Usnea Sp. | Feb. 8/85 | 85-2059 | T-1 | 15.27 | 3 | 15 | 19 ± 2 | | | | |
| Usnea Sp. | Feb. 8/85 | 85-2061 | T-1 | 16.39 | 3 | 19 | 14 ± 2 | | | | |
| Usnea Sp. | Jul. 3/85 | 85-2086 | T-3 | 14.50 | 3 | 41 | 84 ± 4 | | | | |
| Usnea Sp. | Jul. 5/86 | 85-2368 | T-1 | 11.11 | 4 | 43 | 19 ± 3 | | | | |
| Usnea Sp. | Jul. 3/85 | 85-2096 | T-17 | 13.29 | 3 | 25 | 43 ± 3 | | | | |
| Usnea Sp. | Jul. 3/85 | 85-2491 | T-5 | 15.15 | 3 | 29 | 12 ± 2 | | | | |
| Usnea Sp. | Jul. 3/85 | 85-2496 | T-4 | 17.58 | 3 | 51 | 79 ± 2 | | | | |
| Usnea Sp. | Jul. 3/85 | 85-2503 | T-1 | 17.75 | 3 | 23 | 19 ± 2 | | | | |
| Usnea Sp. | Jul. 5/86 | 86-13808 | T-3 | 18.31 | 2 | 25 | 41 ± 3 | 9 ± 3 | < 566 | 374 ± 44 | 12 ± 4 |
| Usnea Sp. | Jul. 5/86 | 86-13818 | T-5 | 12.37 | 2 | 12 | 92 ± 3 | 14 ± 3 | < 784 | 459 ± 42 | 22 ± 6 |
| Usnea Sp. | Jul. 5/86 | 86-13826 | T-8 | 24.99 | 2 | 19 | 38 ± 2 | 10 ± 2 | < 463 | 305 ± 33 | 16 ± 5 |
| Usnea Sp. | Jul. 5/86 | 86-13834 | T-9 | 23.00 | 2 | 18 | 62 ± 3 | 11 ± 3 | < 548 | 308 ± 36 | 13 ± 5 |
| Usnea Sp. | Jul. 5/86 | 86-13838 | T-4 | 11.02 | 3 | 24 | 89 ± 4 | 11 ± 2 | < 603 | 326 ± 35 | 8 ± 4 |
| Usnea Sp. | Jul. 5/86 | 86-13841 | T-3 | 14.67 | 3 | 17 | 75 ± 3 | 18 ± 2 | < 418 | 707 ± 35 | 11 ± 4 |
| Usnea Sp. | Jul. 5/86 | 86-13844 | T-2 | 13.19 | 2 | 15 | 92 ± 4 | 16 ± 3 | < 1221 | 444 ± 45 | 11 ± 5 |
| Usnea Sp. | Jul. 5/86 | 86-13848 | T-1 | 13.23 | 2 | 12 | 74 ± 5 | 23 ± 3 | < 1161 | 1110 ± 53 | 17 ± 5 |
| Usnea Sp. | Jul. 5/86 | 86-13850 | T-6 | 29.43 | 1 | 11 | 83 ± 2 | 12 ± 1 | < 333 | 340 ± 15 | 15 ± 2 |
| Usnea Sp. | Jul. 5/86 | 86-13852 | T-7 | 14.47 | 2 | 16 | 82 ± 4 | 12 ± 4 | < 921 | 426 ± 58 | 13 ± 8 |

and K-40 were detected. Samples collected in 1986 were analyzed as soon as they were received in order to identify the effects of Chernobyl input and several short lived radionuclides were detected in addition to Cs-137 and K-40.

The Cs-137 distribution in *C. Arbuscula*, varies greatly with geographical distribution (Figure 33). For example, values at Digby alone ranged from 23 Bq/kg to 115 Bq/kg in 1985. The average activity found in N.B. was 63 ± 32 Bq/kg compared to 60 ± 50 Bq/kg found at sampling sites near Digby. This differs from samples collected in 1984 when Cs-137 levels were significantly higher in N.B. (119 Bq/kg compared to 33 Bq/kg in Digby). Elevated levels of Cs-137 (avg. 113 ± 54) were again detected in *C. Arbuscula* in New Brunswick in 1986. These results and the high standard deviations reflect the general variability in Cs-137 measurements in lichen.

Levels of radionuclides measured in *Usnea sp.* which were collected in New Brunswick are presented in Table 24. The average level of Cs-137 found in *Usnea sp.* was 33 ± 29 Bq/kg in 1985 and 73 ± 20 Bq/kg in 1986. Cesium-137 activities in *Usnea* sp. in 1986 were greater by a factor of 2 compared to the activities measured in 1985, 1984 (35 Bq/kg) and 1983 (45 Bq/kg). Figure 33 illustrates the geographical distribution in Cs-137 levels in *Usnea sp.* for 1985 and 1986 and depicts a general increase in Cs-137 activities in 1986 from site to site. This increase can be related to the Chernobyl accident (Chapter 7).

Samples of both *Usnea sp.* and *C. Arbuscula* were collected monthly at site T-1 when possible during 1985 and the results are plotted in Figure 34 along with the monthly rainfall for the same period. Results for 1985 were based on only 3 data points and did not show the relationship between Cs-137 and rainfall illustrated for *C. Arbuscula* in 1984.

The relationship between Cs-137 and K-40 for both *Usnea sp.* and *C. Arbuscula* was examined again (Figure 35) and no correlation between Cs-137 and K-40 was found. It is interesting to note that in 1985 when, Cs-137 levels in both species of lichen were similar, the levels of K-40 were also the same; i.e. average activity of 98 Bq/kg in *Usnea sp.* and of

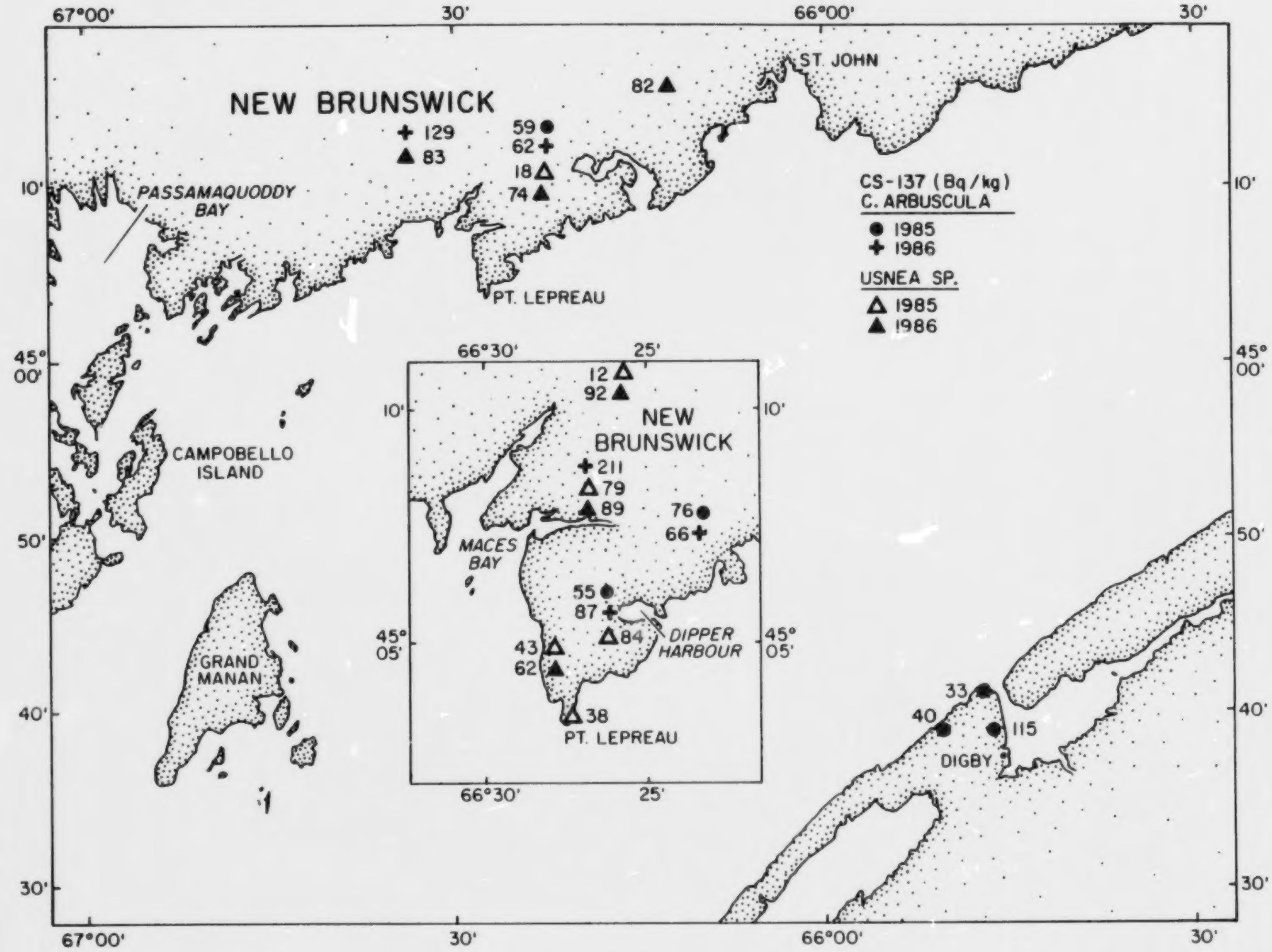

67°00'
30'
66°00'
30'
10'
45° 00'
50'
40'
30'
NEW BRUNSWICK
PASSAMAQUODDY BAY
CAMPOBELLO ISLAND
GRAND MANAN
PT. LEPREAU
ST. JOHN
DIGBY
+ 129
▲ 83
59 ●
62 +
18 △
74 ▲
82 ▲
33
40
115
CS-137 (Bq/kg)
C. ARBUSCULA
● 1985
+ 1986
USNEA SP.
△ 1985
▲ 1986
66°30'
25'
45° 05'
NEW BRUNSWICK
12 △
92 ▲
+ 211
△ 79
▲ 89
76 ●
66 +
MACES BAY
55 ●
87 +
△ 84
DIPPER HARBOUR
43 △
62 ▲
△ 38
PT. LEPREAU

Figure 33. Geographical distribution of Cs-137 activity in lichen species collected in 1985 and 1986.

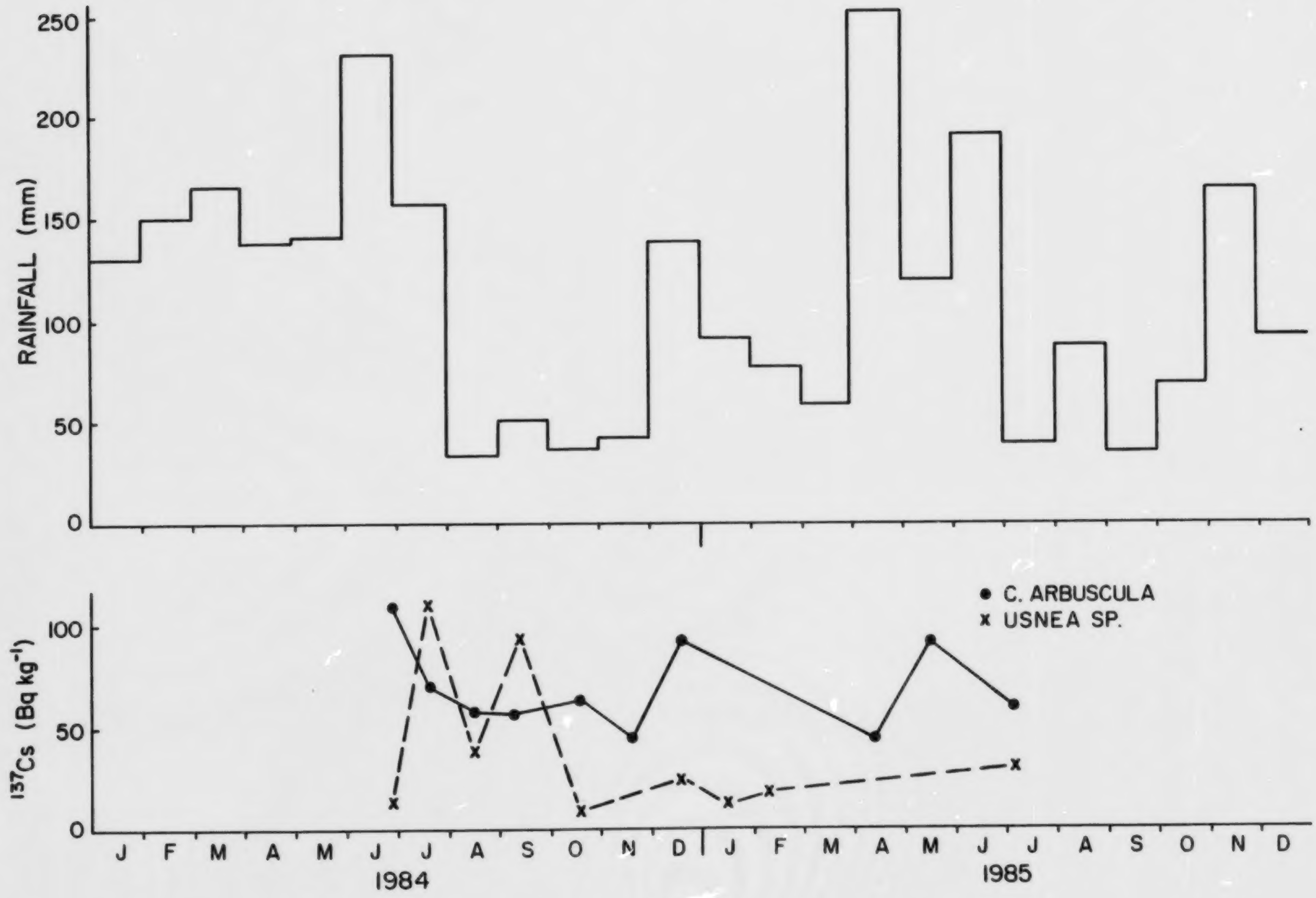


Figure 34. Time series constructed for lichen samples collected at site #1, Cs-137 and rainfall.

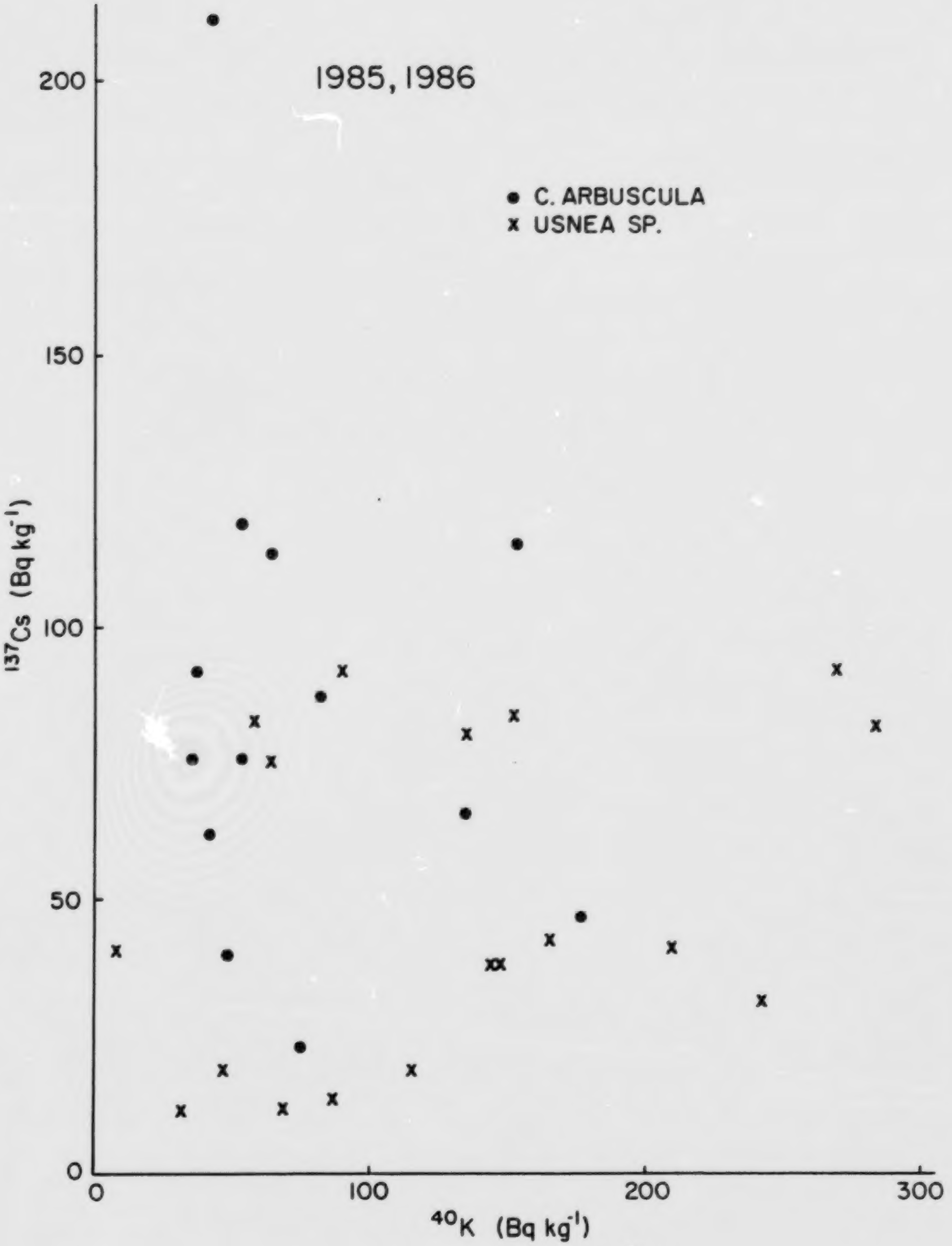


**Figure 35.** K-40 activity versus Cs-137 activity for lichen samples collected during 1985 and 1986.

98 Bq/kg in *C. Arbuscula*, while in 1986 K-40 levels are lower and Cs-137 levels higher in *C. arbuscula*.

Comparisons of Cs-137 activities in ground lichen vs. arboreal lichen at the same location (Figure 36) show that there is no strong correlation of Cs-137 levels in these species. Differences in Cs-137 content are probably a function of their different habitats. Ground lichen is able to trap nutrients from rainwater. Arboreal lichen obtains most of its nutrients directly from air moisture and thus generally contains lower levels of contaminants. Lichen plants will have different collection efficiencies for airborne contaminants depending on their immediate micro-environment. However normalizing each Cs-137 activity to the Be-7 activity for that lichen plant corrects for the collection efficiency and yields a value proportional to the Cs-137 flux (Ellis and Smith , 1987). As illustrated in Figure 36, the Cs-137/Be-7 ratios in arboreal and ground lichen are reasonably well correlated (n=7, r=0.63) indicating that the Cs-137 source is the same for each location.

In summary, Cs-137 activities measured in lichen samples collected during 1985 and 1986 were within activities measured during the course of the monitoring program. There was a measurable increase in Cs-137 activities in samples collected during 1986 in both species at the majority of sampling sites due to the input from the Chernobyl accident.

### 5.2.2 Birds

Birds are not particularly suited as indicator species for radionuclide uptake because of their mobility over a comparatively wide area. They do, however occupy an important position in the food web, particularly in the Bay of Fundy region, which is a critical location for foraging for a large number of shore birds before their migration to southern regions (Smith *et al.* 1982).

Two bird species were collected during 1985 for radionuclide analysis. Three samples of purple sandpiper (*Arquatella maratima*) were collected in March from the Maces Bay area and two samples of common eider (*Somateria mollissima*) were collected, one in

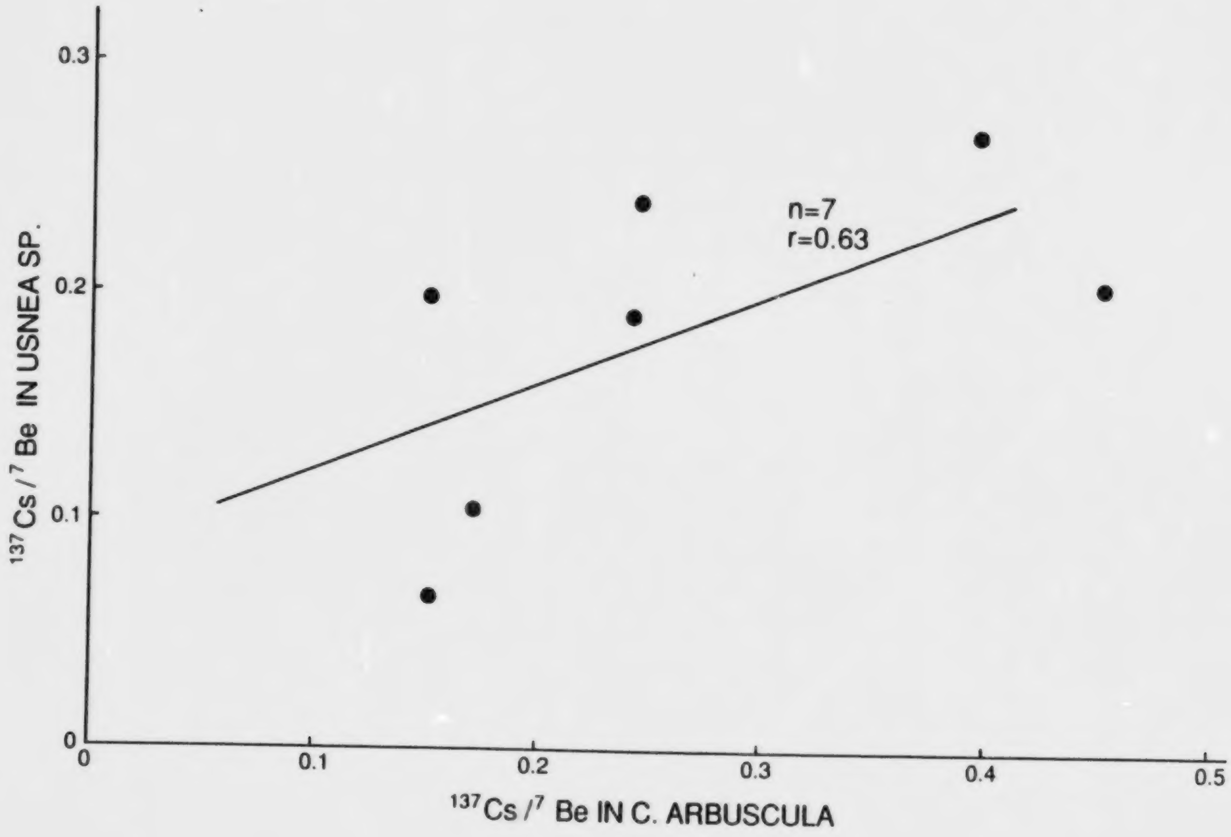


Figure 36. Cs-137/Be-7 in arboreal lichen (Usnea sp.) versus Cs-137/Be-7 activity in ground lichen (C. Arbuscula).

October from the Brothers Rocks near Maces Bay and one in December from Indian Point at St. Andrews. All samples were dissected by the Canadian Wildlife Service into samples of muscle, gut, bone and liver. The results for all samples are presented in Table 25. Only Cs-137 was detected in any of the samples and activities ranged <1 to 8 Bq/kg i.e., similar in range to Cs-137 levels detected in bird samples collected in 1980 (Smith *et al.* 1982).

## 5.3 Tritium in Aquatic and Terrestrial Systems

The movement of tritium through ecosystems is complex and dependent on the medium in which the tritium is fixed. In general, the levels of tritium found in biological systems mirror tritium activities in the surrounding media and concentration factors normally range from zero to slightly more than one. Adams *et al.* 1979 reported that tritium levels in a contaminated freshwater marsh ecosystem generally followed marsh water tritium levels. Harrison *et al.* (1971) found that both cattails *Typha angustfolia* and filamentous algae, *Pithophora sp.* grown in a contaminated pool reached tritium levels from 70 to 100% of the original pool water but no concentration effects were observed.

Tritium activities measured in the terrestrial and aquatic environments during 1985/86 are presented in Table 26. Included are the results from a February 1986 field trip undertaken in response to a boiler tube leak. These results will be discussed in chapter 6. The results indicate a small increase in tritium activities in plant species collected in the vicinity of the NGS in response to increased tritium emissions from the NGS (Table 1). Figure 37 illustrates both the distribution of tritium activities in the Point Lepreau area for 1985/86 and the prevailing wind patterns at the time of sampling. Higher levels of tritium are detected consistently in plants collected at Dipper Harbour compared to Welch's Cove owing to the high incidence of winds from the southwest. Figure 37 shows that the influence of emissions from the NGS has extended to AMS #1 with slightly elevated levels of H-3 being reported for plant samples collected from nearby sites.

Table 25. Radionuclide results for bird samples collected near Point Lepreau area and St. Andrew's, N.B.

| Sample Type | Collection Date | Sample No. | Component | Sample | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Site | Wt(g) | Geom # | % $H_2O$ | Cs-137 Bq/kg | Cs-134 Bq/kg |
| Purple Sandpiper | 1980 | - | Muscle | - | - | - | - | <5 | |
| | | | Liver | - | - | - | - | <4 | |
| | | | Bone | - | - | - | - | <7 | |
| | | | Gut | - | - | - | - | <4 | |
| Common Eider | 1980 | | Muscle | - | - | - | - | <2 | |
| | | - | Liver | - | - | - | - | <4 | |
| | | | Bone | - | - | - | - | <3 | |
| | | | Gut | - | - | - | - | <2 | |
| Purple Sandpiper | 21 Mar 85 | 85-2066 | Muscle | St. Andrew's | 3.85 | 5 | 72 | 5±1 | |
| Purple Sandpiper | 21 Mar 85 | 85-2069 | Gut | St. Andrew's | 4.47 | 5 | 70 | <10 | |
| Purple Sandpiper | 21 Mar 85 | 85-2070 | Muscle | St. Andrew's | 3.41 | 5 | 72 | 4±2 | |
| Purple Sandpiper | 21 Mar 85 | 85-2073 | Gut | St. Andrew's | 3.00 | 5 | 73 | 6±2 | |
| Purple Sandpiper | 21 Mar 85 | 85-2074 | Muscle | St. Andrew's | 3.22 | 5 | 73 | <10 | |
| Purple Sandpiper | 21 Mar 85 | 85-2077 | Gut | St. Andrew's | 2.49 | 5 | 74 | 8±4 | |
| Purple Sandpiper | 21 Mar 85 | | Comp Live | St. Andrew's | 3.22 | 5 | 73 | <10 | |
| Purple Sandpiper | 21 Mar 85 | | Comp Bone | St. Andrew's | 7.81 | 4 | 58 | <4 | |
| Common Eider | 8 Oct 85 | 13889 | Muscle | Maces Bay | 3.56 | 3 | 73 | 1.0±0.5 | |
| Common Eider | 8 Oct 85 | 13882 | Bone | Maces Bay | 12.33 | 4 | 34 | 3±1 | |
| Common Eider | 8 Oct 85 | 13883 | Liver | Maces Bay | 21.83 | 4 | 69 | <2 | |
| Common Eider | 8 Oct 85 | 13884 | Gut | Maces Bay | 60.03 | 2 | - | <1 | |
| Common Eider | 13 Dec 85 | 13885 | Liver | Indian Point | 22.61 | 4 | 70 | 2±1 | |
| Common Eider | 13 Dec 85 | 13886 | Bone | Indian Point | 18.91 | 5 | 43 | <1 | |
| Common Eider | 13 Dec 85 | 13887 | Muscle | Indian Point | 38.73 | 3 | 72 | 1.1±0.4 | |
| Common Eider | 13 Dec 85 | 13888 | Gut | Indian Point | 25.92 | 3 | 77 | <2 | |

Table 26. Comparison of tritium levels found in aquatic and terrestrial systems.

| Sample Type | Collection Date | Sample # | Component | Collection Site | H-3 (Bq/1) |
|---|---|---|---|---|---|
| Bullrushes | July 3 85 | 85-2080 | Leaves | T-3 | 109 ± 4 |
| Bullrushes | July 3 85 | 85-2090 | Leaves | T-5 | 2 ± 2 |
| Bullrushes | July 3 85 | 85-2480 | Leaves | T-8 | 21 ± 3 |
| Bullrushes | July 3 85 | 85-2487 | Leaves | T-9 | 9 ± 3 |
| Bullrushes | July 3 85 | 85-2494 | Leaves | T-4 | 11 ± 3 |
| Bullrushes | July 3 85 | 85-2501 | Leaves | T-1 | 8 ± 3 |
| Bullrushes | Feb 26 86 | 13446 | Heads | T-4 | 8 ± 3 |
| Bullrushes | July 5 86 | 13823 | Heads | T-8 | 58 ± 3 |
| Bullrushes | July 5 86 | 13830 | Heads | T-9 | 7 ± 3 |
| Bullrushes | July 5 86 | 13836 | Heads | T-4 | 9 ± 3 |
| Bullrushes | July 5 86 | 13846 | Heads | T-1 | 12 ± 3 |
| Sphagnum | July 3 85 | 85-2402 | Whole | T-5 | 4 ± 3 |
| Sphagnum | July 3 85 | 85-2405 | Whole | T-8 | 26 ± 3 |
| Sphagnum | July 3 85 | 85-2078 | Whole | T-3 | 33 ± 3 |
| Sphagnum | July 5 86 | 13811 | Whole | T-5 | 7 ± 3 |
| Sphagnum | July 5 86 | 13803 | Whole | T-3 | 33 ± 3 |
| Sphagnum | July 5 86 | 13821 | Whole | T-8 | 36 ± 3 |
| Lichen | Feb 8 85 | 85-2060 | Usnea | T-8 | 9 ± 3 |
| Lichen | July 3 85 | 85-2497 | Usnea | T-4 | 9 ± 3 |
| Lichen | July 3 85 | 85-2336 | Usnea | T-1 | < 3 |
| Lichen | July 3 85 | 85-2409 | Usnea | T-2 | 4 ± 3 |
| Lichen | Feb. 26 86 | 13419 | Usnea | T-8 | 526 ± 8 |
| Lichen | Feb. 26 86 | 13436 | Usnea | T-3 | 7 ± 4 |
| Lichen | Feb. 26 86 | 13445 | Usnea | T-4 | < 2 |
| Lichen | Feb. 26 86 | 13450 | Usnea | T-5 | 9 ± 3 |
| Lichen | Feb. 26 86 | 13403 | Usnea | T-2 | < 3 |
| Spruce | Feb. 26 86 | 13404 | Needles | T-2 | 12 ± 3 |
| Spruce | Feb. 26 86 | 13417 | Needles | T-8 | 550 ± 3 |
| Spruce | Feb. 26 86 | 13418B | Needles | T-8 | 325 ± 5 |
| Spruce | Feb. 26 86 | 13443 | Needles | T-4 | 24 ± 3 |
| Spruce | Feb. 26 86 | 13444 | Needles | T-4 | 50 ± 3 |
| Spruce | Feb. 26 86 | 13405 | Needles | T-2 | 2 ± 3 |
| Spruce | Feb. 26 86 | 13424 | Needles | T-1 | 4 ± 3 |
| Spruce | Feb. 26 86 | 13425 | Needles | T-1 | 7 ± 3 |
| Spruce | Feb. 26 86 | 13426 | Needles | T-8 | 129 ± 4 |
| Fir | Feb. 26 86 | 13434 | Needles | T-3 | 159 ± 4 |
| Fir | Feb. 26 86 | 13448 | Needles | T-5 | 18 ± 3 |
| Fir | Feb. 26 86 | 13433 | Needles | T-4 | 206 ± 4 |
| Fir | Feb. 26 86 | 13449 | Needles | T-5 | 18 ± 3 |
| Alder | Oct. 2 86 | 13478 | Leaves | T-8 | 25 ± 3 |
| Iris | July 5 86 | 13806 | Whole | T-3 | 12 ± 3 |
| Iris | July 5 86 | 13814 | Whole | T-5 | 9 ± 3 |
| Iris | July 5 86 | 13824 | Whole | T-8 | 18 ± 3 |
| B. Berry | July 5 86 | 13819 | Leaves | T-5 | 4 ± 3 |
| B. Berry | July 5 86 | 13827 | Leaves | T-8 | 13 ± 3 |
| Golden Rod | Oct. 2 86 | 13479 | Whole | T-8 | 31 ± 3 |
| Dog Berry | Oct. 2 86 | 13480 | Berries | T-8 | 47 ± 3 |

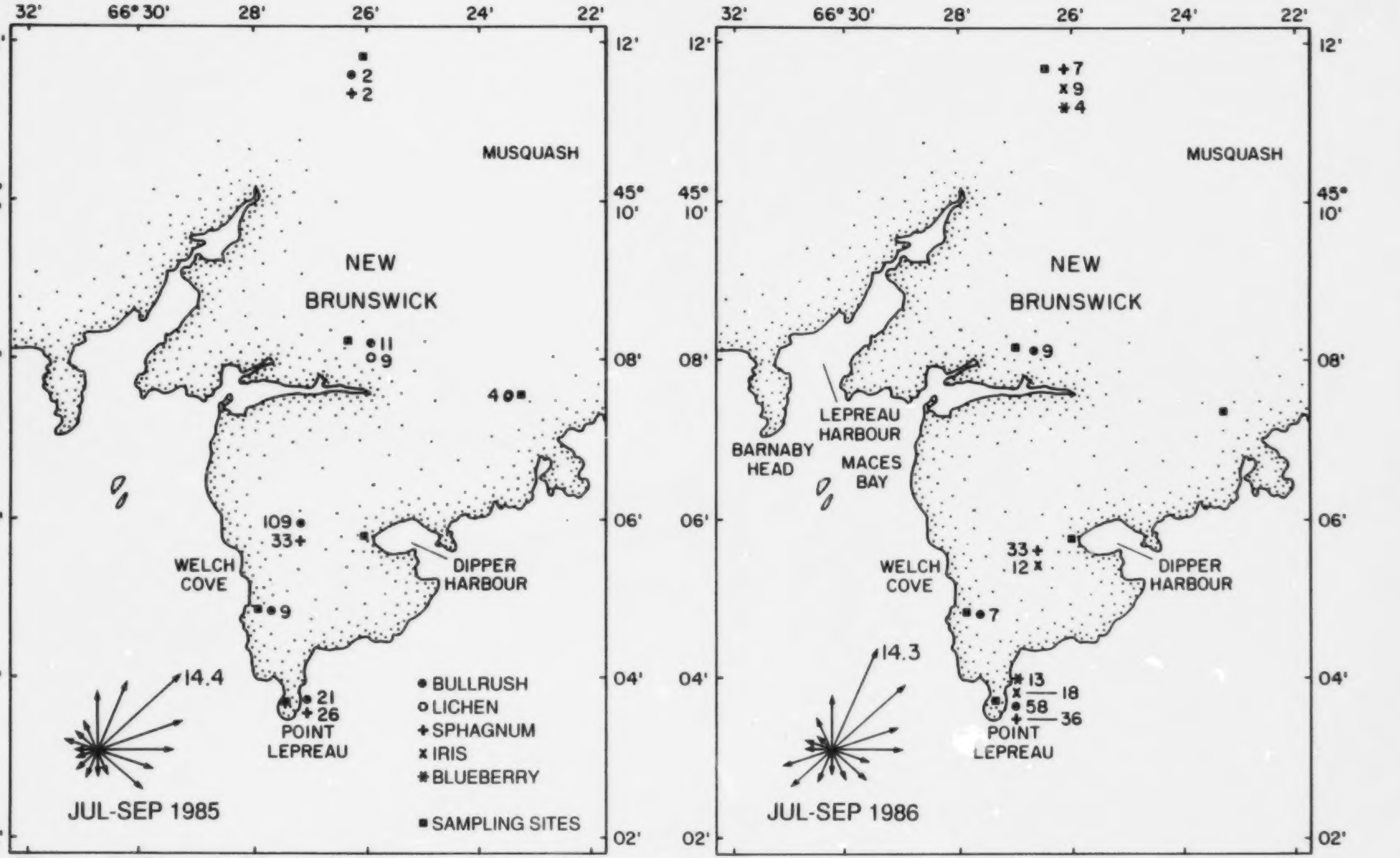

32'
66° 30'
28'
26'
24'
22'
12'
45° 10'
08'
06'
04'
02'
MUSQUASH
NEW BRUNSWICK
2
2
11
9
4
109
33
9
21
26
WELCH COVE
DIPPER HARBOUR
POINT LEPREAU
14.4
JUL-SEP 1985
● BULLRUSH
○ LICHEN
+ SPHAGNUM
x IRIS
* BLUEBERRY
■ SAMPLING SITES
7
9
4
9
LEPREAU HARBOUR
BARNABY HEAD
MACES BAY
33
12
7
13
18
58
36
14.3
JUL-SEP 1986

Figure 37. Tritium activities measured in plant samples collected in the Point Lepreau region in 1985 and 1986.

## 6.0 POINT LEPREAU LEAK SURVEY

A boiler tube leak was detected on December 24, 1985, while the reactor was operating at full power. The leak rate of $D_2O$ was reduced and stabilized at approximately 0.5 kg/hr and it was decided to repair the leak during a scheduled shut down of the reactor in April 1986. Tritium was the radionuclide released in the greatest quantities although other radionuclides were also released (Table 1). The gaseous and liquid reactor releases of tritium are illustrated for the time period of May 1985 to September 1986 in Figure 38. The large increase in January reflects the initial releases owing to the leak. Using a monthly cooling water volume of $7.0 \times 10^{10}\ \ell$ and a total release of 28 TBq in January, 12 TBq in February and 4 TBq in March, the concentration of tritium in the liquid effluent prior to dilution in the Bay of Fundy is calculated to be 400 Bq/$\ell$ in January, 170 Bq/$\ell$ in February and 57 Bq/$\ell$ in March.

A field trip was organized for February 25-27, 1986, to collect biological and water samples, and to conduct a thermal plume study near the reactor outfall in order to assess any environmental impact associated with the release. In addition, the constant release of tritium in liquid effluent provided a unique opportunity to study the behaviour of tritium in the Bay of Fundy and relate its distribution in the plume to that of temperature under steady state conditions. The results from the thermal plume study are given in Section 2.4.1.

Samples of freshwater, snow, arboreal lichen (Usnea), spruce needles (both on the side of the tree facing the reactor and away from the reactor) and shrub leaves were collected at most of the terrestrial and aquatic sample sites; T-1 to 5 and T-8 and T-9. Seaweed samples were collected at I-15 (Welch's Cove), the tip of Point Lepreau, I-1 (Indian Cove) and I-17 (Duck Cove) (Figure 31). Large volume water samples were collected at T-1, T-3 and at the reactor outfall. A sample of cattail was collected at T-4. Samples were processed and analyzed as described in Section 4.2. Air samples were collected in the normal manner during this time period (i.e. one week per month) and analyzed as described in Section 3.2.

Results for the tritium analyses of biological samples, freshwater, snow and air moisture are given in Table 27. The geographical configuration of these data is illustrated in

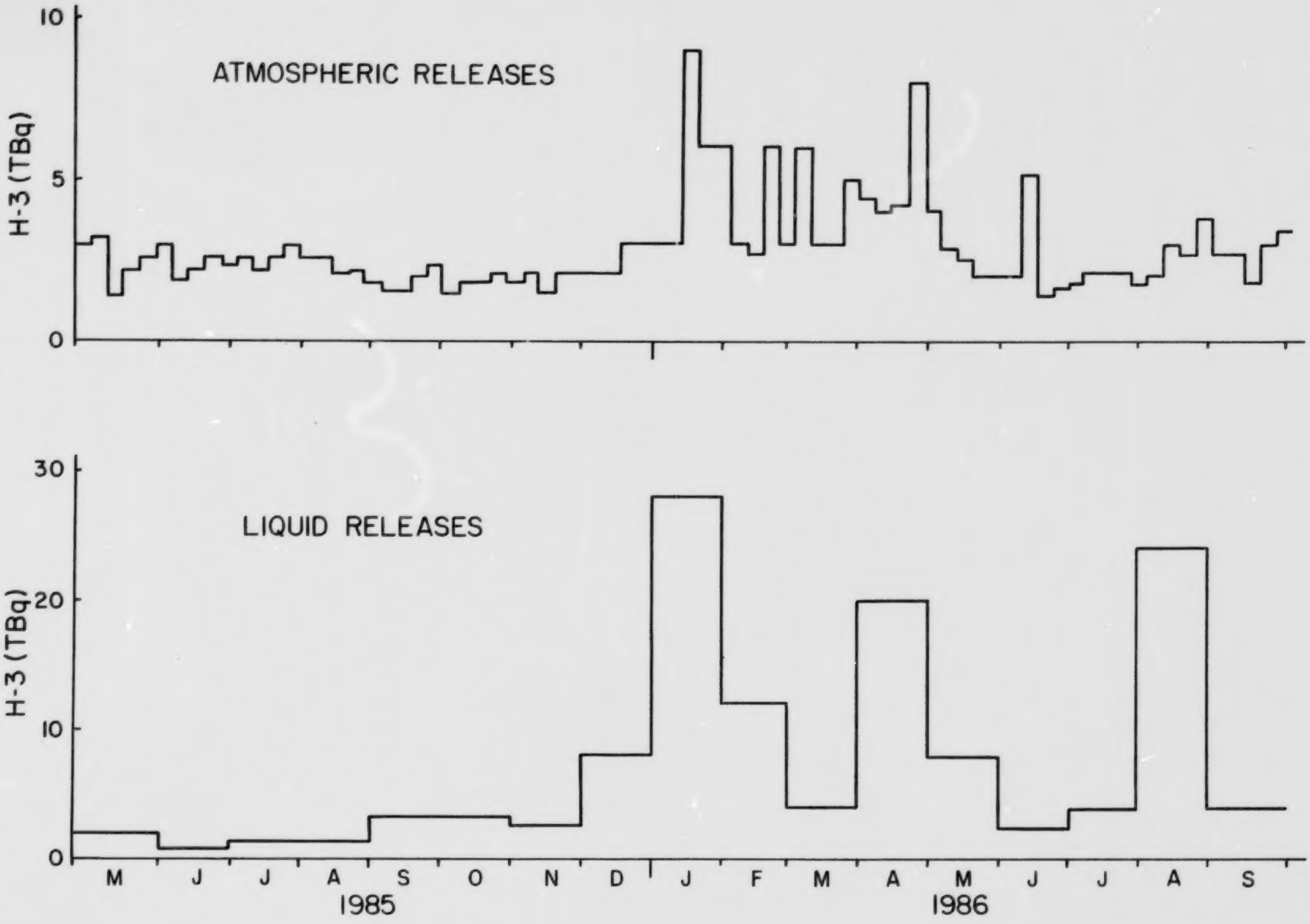


Figure 38. Liquid and gaseous tritium releases from the Point Lepreau nuclear generating station for 1985 and 1986.

Table 27. Tritium (Bq/ℓ) levels in samples collected in February, 1986.

| Sample Type | Site T-1 | Site T-2 Retreat Lake | Site T-3 Dipper Harbour | Site T-4 | Site T-5 | I-16 Indian Cove | Site T-8 I-6 Light house | Site T-9, I-15 Welch's Cove | I-17 Duck Cove |
|---|---|---|---|---|---|---|---|---|---|
| Freshwater |  | 4±3 |  |  |  | 4±3 |  |  | 68±4 (unflowing stream) |
| Snow |  | 6±3 | 8±3 | 7±3 |  |  | 56±4<br><6 | 4±3 |  |
| Usnea | 7±3 | 3±3 | 7±4 | <2 | 9±3 |  | 538±8 |  |  |
| Spruce facing | 4±3 | 12±3 | 202±4 | 24±3 | 15±3 |  | 319±5 |  |  |
| Spruce away |  | 3±4 | 159±4 | 49±3 | 18±3 |  | 550±3 |  |  |
| Leaves |  |  | 10±3 |  |  |  |  |  |  |
| Cattail head |  |  |  | 8±3 |  |  |  |  |  |
| Ascophyllum |  |  |  |  |  | 5±3 | 4±3<br>5±3 | <4 | 6±3 |
| Fucus |  |  |  |  |  |  | 4±3<br>3±3<br>3±3 | <3 | 4±3 |
| Laminaria |  |  |  |  |  |  | 5±3 |  |  |
| Air | Digby |  | Stn #2 |  | Stn #1 |  | Stn #3 | Stn #4 |  |
| Dec | 3±2 |  | 14±2 |  | -- |  | 145±3 | 39±4 |  |
| Jan | 7±3 |  | 28±2 |  | 20±2 |  | -- | -- |  |
| Feb | -- |  | 14±2 |  | 15±2 |  | 124±3 | 27±2 |  |
| Mar | 6±3 |  | 46±3 |  | 10±2 |  | 52±3 | 17±2 |  |
| Apr | 3±3 |  | 45±3 |  | 12±2 |  | 394±5 | 56±3 |  |

Figure 39. Included in Figure 39 are wind roses (distance) for the month of January and February.

Air concentrations give an indication of the distribution of atmospherically released tritium and the degree of exposure of terrestrial and aquatic organisms to tritium. The tritium data for air in Bq/ℓ indicate that the maximum activity occurred in January at most locations and decreased through February and March. Activities were highest closest to the reactor at the lighthouse (T-8), while elevated tritium levels were also measured at other sites.

The same pattern noted for air moisture samples is also observed for the biological, water and snow samples. The highest levels of tritium were measured at the lighthouse, with reduced levels measured at Dipper Harbour and Welch's Cove. Elevated levels of tritium were also measured at sites further away, T-3 (Retreat Lake) and T-1 (Musquash). Spruce needles contain the highest levels of tritium with the maximum level of 550 Bq/ℓ measured at the lighthouse. There was no significant difference in tritium levels between spruce needles facing toward or away from the reactor. An Usnea sample collected at the lighthouse exhibited very high levels of tritium (536 Bq/ℓ) although levels in Usnea at other stations were generally low. Tritium levels in biological samples tended to be higher than those measured in air, but that may be a transient response owing to the different sampling times for air, terrestrial and aquatic samples. The tritium levels in seaweed samples were low, and within the range of pre-operational levels, even close to the outfall location at Duck Cove.

No radionuclides from the reactor were measured either dissolved or in particulate phases of freshwater systems (Table 20). The levels of Cs-137 measured in seawater samples (2.98 to 4.25 mBq/ℓ) were in the range of pre-operational levels while levels for marine particulate material were below the detection limit.

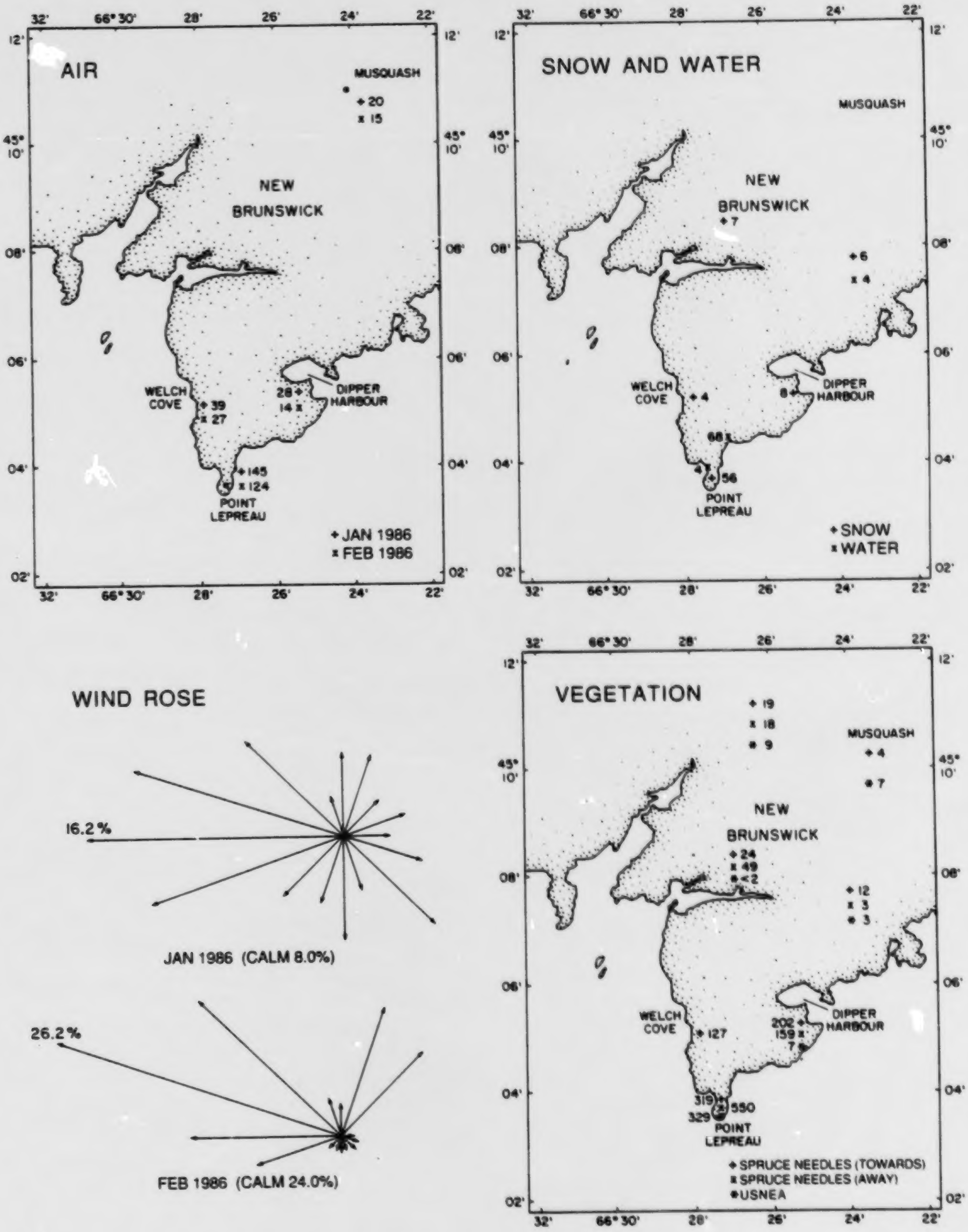

AIR
MUSQUASH
+ 20
x 15
NEW BRUNSWICK
WELCH COVE
+ 39
x 27
28 +
14 x
DIPPER HARBOUR
+ 145
x 124
POINT LEPREAU
+ JAN 1986
x FEB 1986
SNOW AND WATER
MUSQUASH
NEW BRUNSWICK
+ 7
+ 6
x 4
WELCH COVE
+ 4
8 +
DIPPER HARBOUR
68 x
4 x
+ 56
POINT LEPREAU
+ SNOW
x WATER
WIND ROSE
16.2 %
JAN 1986 (CALM 8.0%)
26.2 %
FEB 1986 (CALM 24.0%)
VEGETATION
+ 19
x 18
* 9
MUSQUASH
+ 4
* 7
NEW BRUNSWICK
+ 24
x 49
* <2
+ 12
x 3
* 3
WELCH COVE
+ 127
202 +
159 x
7 *
DIPPER HARBOUR
319
329
550
POINT LEPREAU
+ SPRUCE NEEDLES (TOWARDS)
x SPRUCE NEEDLES (AWAY)
* USNEA
32'
66° 30'
28'
26'
24'
22'
12'
45° 10'
08'
06'
04'
02'

**Figure 39.** Tritium levels in plant samples collected from the Point Lepreau area during the leak survey in February 1986.

## 7.0 CHERNOBYL FALLOUT

### 7.1 Introduction

As a consequence of the accident at the nuclear power plant at Chernobyl, near Kiev in the USSR, which began on April 26, 1986, large quantities of radioactivity were released to the atmosphere. The heat generated both by the fire in the graphite moderator of the reactor and by the core itself caused the radioactive plume to rise thousands of meters, thereby promoting the dispersal of the radioactivity on a global scale.

Winds initially carried the plume in a northwesterly direction toward Finland and Sweden where it was first detected early on April 27 as a consequence of elevated levels of radioactivity measured at a Swedish nuclear power plant (Devell *et al.* 1986). The plume remained over northern Europe for the next two days as a result of stagnant meteorological conditions as intermittent rainfall increased its deposition (ApSimon & Wilson, 1986). During the next few days, dispersion of the plume occurred throughout Europe. The plume was first measured in Hungary (Csongor *et al.* 1986) and Paris (Thomas & Martin, 1986) on April 29 and in Great Britain on May 2 (Fry *et al.* 1986, Hill *et al.* 1986). The plume was also detected in northern Canada on May 2-3 (Health and Welfare, 1987), and moved south into central and eastern Canada on May 6-7. At the same time, a second component of the plume ascended to higher altitudes and was transported with prevailing winds in an easterly direction over the USSR. In the following weeks, the radioactive cloud was transported around the world initially reaching Japan on May 3 (Nishizama *et al.* 1986), the USA on May 9 (Larsen *et al.* 1986) and southern Canada as early as May 7-8 (Environmental Health Directorate, 1987). The cloud was again detected over Paris between May 10 and 17 and was identified as the second pass of the plume (Thomas & Martin, 1986).

Fallout products from Chernobyl deposited in the vicinity of the Point Lepreau NGS could be mistaken for reactor effluent, as was done when the plume was initially detected in Sweden. These fallout products must be identified and quantified in order to separate the two sources of radioactive inputs to the environment. The detection of fallout provides a good test of the sensitivity of the analyses required for the detection of radionuclides released from the Point Lepreau NGS under routine and nonroutine situations. In addition, analysis of food was carried out by the AERU laboratory at the request of the Radiation Protection Bureau (RPB) of Health and Welfare Canada in order to aid in their public health monitoring program. Samples of milk, rhubarb and canned mushrooms were analyzed and these and all other results were made available to the RPB.

## 7.2 Air Monitoring

### 7.2.1 Sampling

Samples of air were collected daily by Health and Welfare Canada to document the arrival and dispersion of the plume in Canada. The radioactive plume detected in northern Canada on May 2-3 moved south into Quebec and eastern Canada on May 6-7. A second plume was first observed in the western half of southern Canada where radionuclides I-131 and Cs-137 were initially detected on May 7-8, arriving in central Canada on May 8-9 and reaching the east coast of Canada by May 9-10. Ruthenium-103 was initially detected several days later. In Figure 40, the distributions of I-131 and Ru-103 air particulate concentrations with time are given for Vancouver, B.C., Ottawa, Ont., Halifax, N.S. (including Greenwood and Digby) and St. John's, Nfld. Activities were higher in the west compared to eastern Canada.

Two of the five air monitoring stations established in the Point Lepreau Environmental Monitoring Program (Station 2 at Dipper Harbour, N.B. and Station 5 at Digby, N.S., see Figure 21 for station locations) were operated at two day intervals collecting air particulate material beginning May 3 in order to closely monitor the transport of Chernobyl radioactivity through eastern Canada. The other air monitoring stations were operated in the normal manner (i.e. one week per month) during this time period. Samples were analyzed as described in Section 3.2.2. The Chernobyl plume was initially detected when I-131 was measured on both the air filters and air cartridges at both stations between

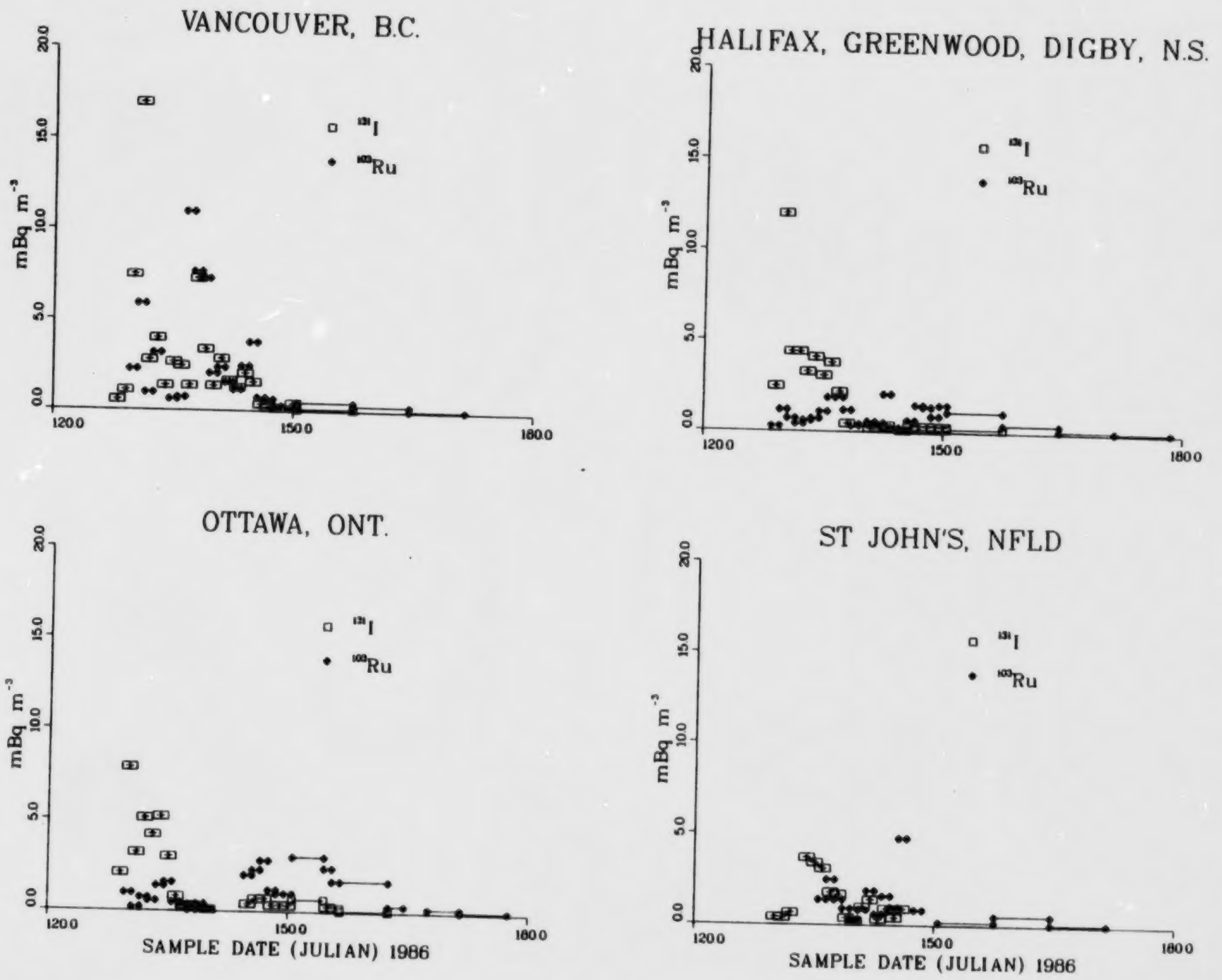


Figure 40. I-131 and Ru-103 air particulate activities from April 30 (Julian day 120) to June 29 (Julian day 180), 1986 for Vancouver, B.C., Ottawa, Ont., Halifax, Greenwood, Digby, N.S. and St. John's, Nfld. (Environmental Health Directorate, 1987.)

May 7 and 9. Air sampling was continued until June 6 when activities fell below detection limits. Sampling was restarted for a short period (June 18-27) to ensure levels had remained below detection limits.

Rain samples were also collected in the Halifax area in May during periods of rain in order to measure fallout levels and to observe the temporal distribution of activity with time during rainstorms. Rainwater samples were analyzed directly in plastic containers using a 25% efficient hyperpure germanium detector.

### 7.2.2 Air Results

A list of radionuclides from Chernobyl measured on air filters with associated data is given in Table 28. The first radionuclides, detected in the samples collected between May 7 and 9, were those of the most volatile elements such as isotopes of iodine (I-131 and I-132), cesium (Cs-137, Cs-136 and Cs-134), tellerium (Te-132) and lanthanum (La-140). Short-lived Te-132 and daughter I-132 and La-140 quickly fell below detection limits while the other radionuclides attained maximum activities shortly after, between May 9-11 and were below detection limits by mid-June. Ruthenium-103, a nuclide of the refractory element Ru, was initially detected several days after the other nuclides appeared and activities peaked much later, in early June. Ruthenium-106 ($t_{1/2} = 368$ d), Zr-95 ($t_{1/2} = 64$ d), Nb-95 ($t_{1/2} = 35$ d), Ce-141 ($t_{1/2} = 32$ d) and Ce-144 ($t_{1/2} = 284$ d), fission products commonly observed after most nuclear weapons tests, were not detected.

The levels of fallout products from Chernobyl measured at the air monitoring stations in the Point Lepreau area are presented in Figures 41, 42 and 43. The activities of particulate Cs-137, Cs-134, Ru-103, Be-7, I-131 and gaseous I-131 in air between April 30 (Julian day 90) and June 29 (Julian day 180) for Dipper Harbour, N.B. and Digby, N.S., are listed in Tables 29 and 30 and illustrated in Figures 41 and 42 respectively. The activities for air monitoring stations 1 (Musquash, N.B), 3 (Point Lepreau lighthouse, N.B.) and 4 (Welch's

Table 28. Measured Radionuclides in Chernobyl Fallout.

| Radionuclide | Half-life | Radiotoxicity | Comment |
|---|---|---|---|
| I-131 | 8.07 d | High | |
| I-132 | 2.26 d | Moderate | daughter of Te-132 |
| Cs-134 | 2.07 y | High | |
| Cs-136 | 13 d | Moderate | |
| Cs-137 | 30.2 y | High | |
| Te-132 | 77.7 h | Moderate | |
| La-140 | 40.2 ;h | Moderate | daughter of Ba-140 ($t_{\frac{1}{2}} = 13$ d) |
| Ru-103 | 39.6 h | Moderate | |

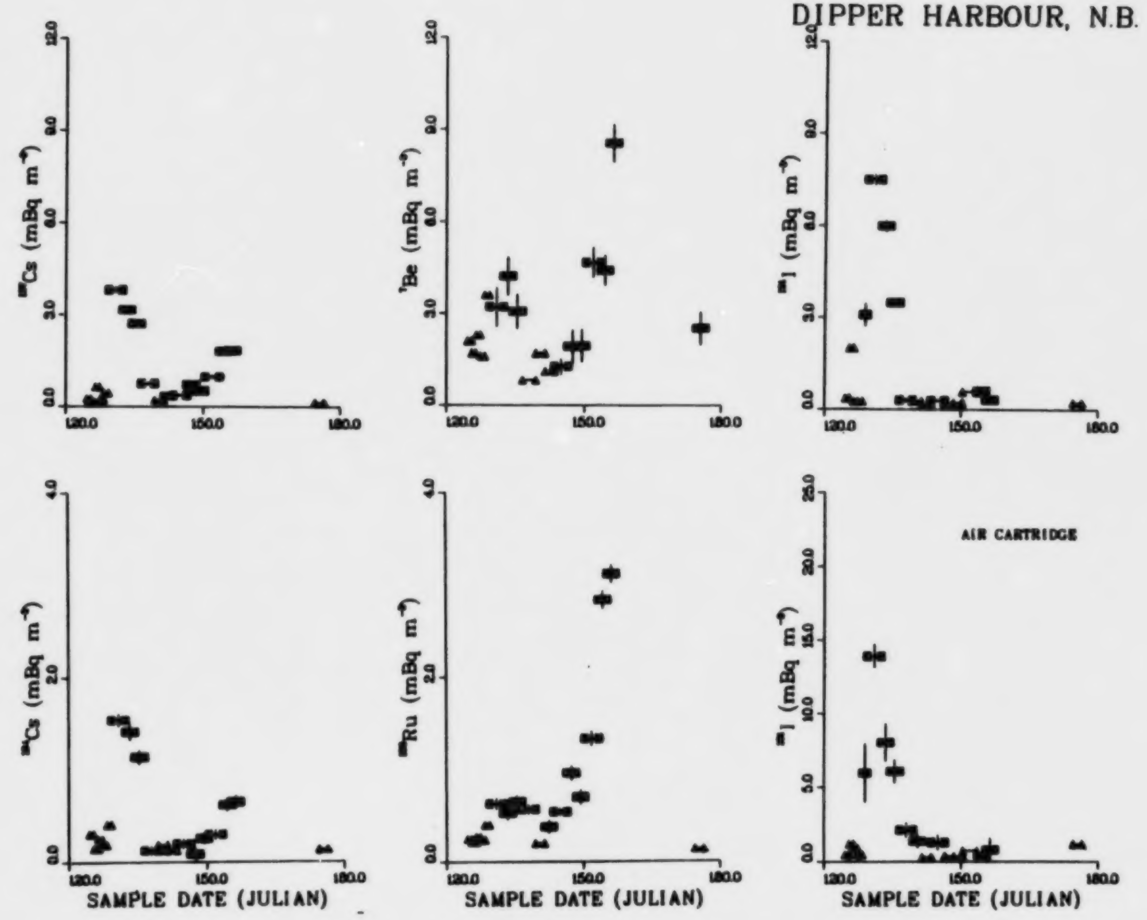


Figure 41. Air particulate activities at Station 2 (Dipper Harbour, N B ) from April 30 (Julian day 120) to June 29 (Julian day 180), 1986. Δ signifies the activity is less than the value illustrated.

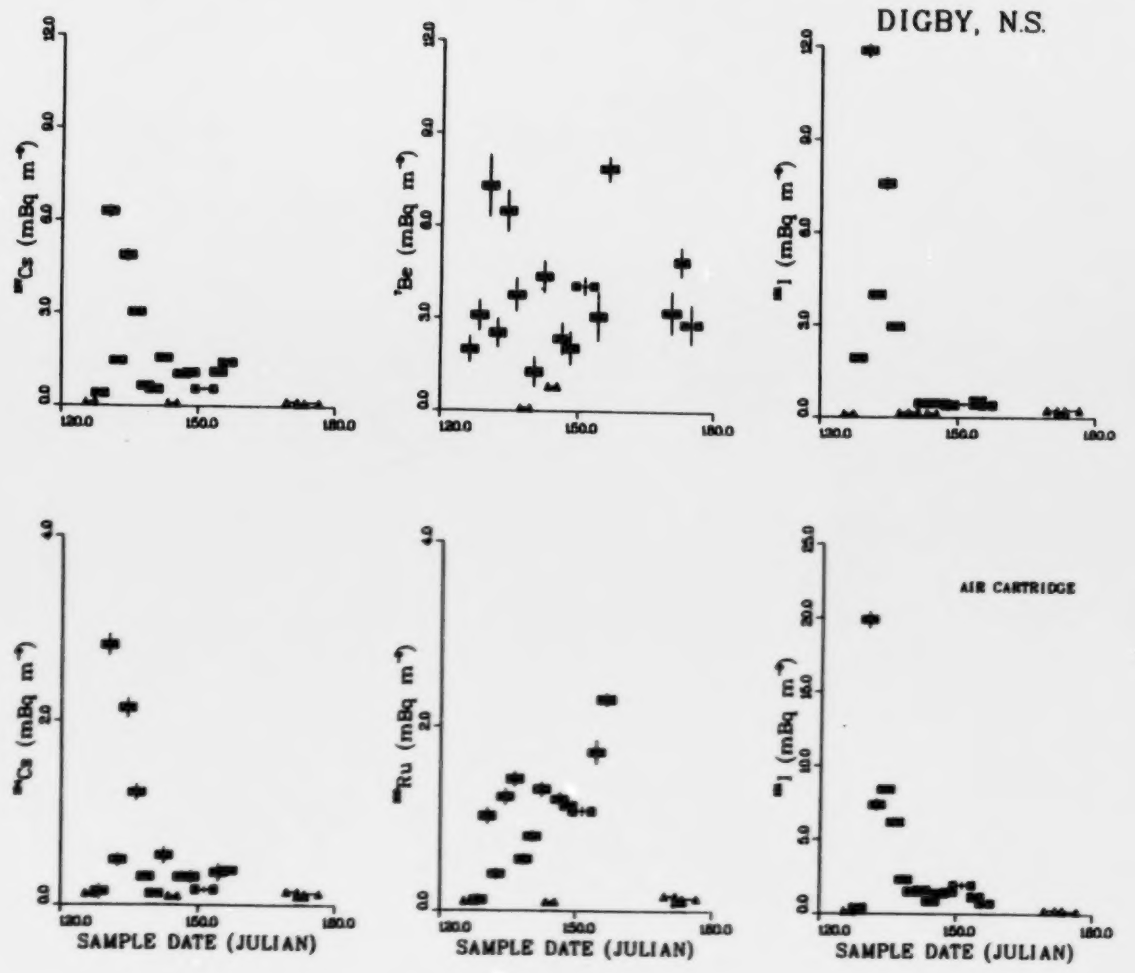


Figure 42. Air particulate activities at Station 5 (Digby, N.S.) from April 30 (Julian day 120) to June 29 (Julian day 180), 1986. Δ signifies that the activity is less than the value illustrated. I-131 activity on air charcoal cartridge is also included.

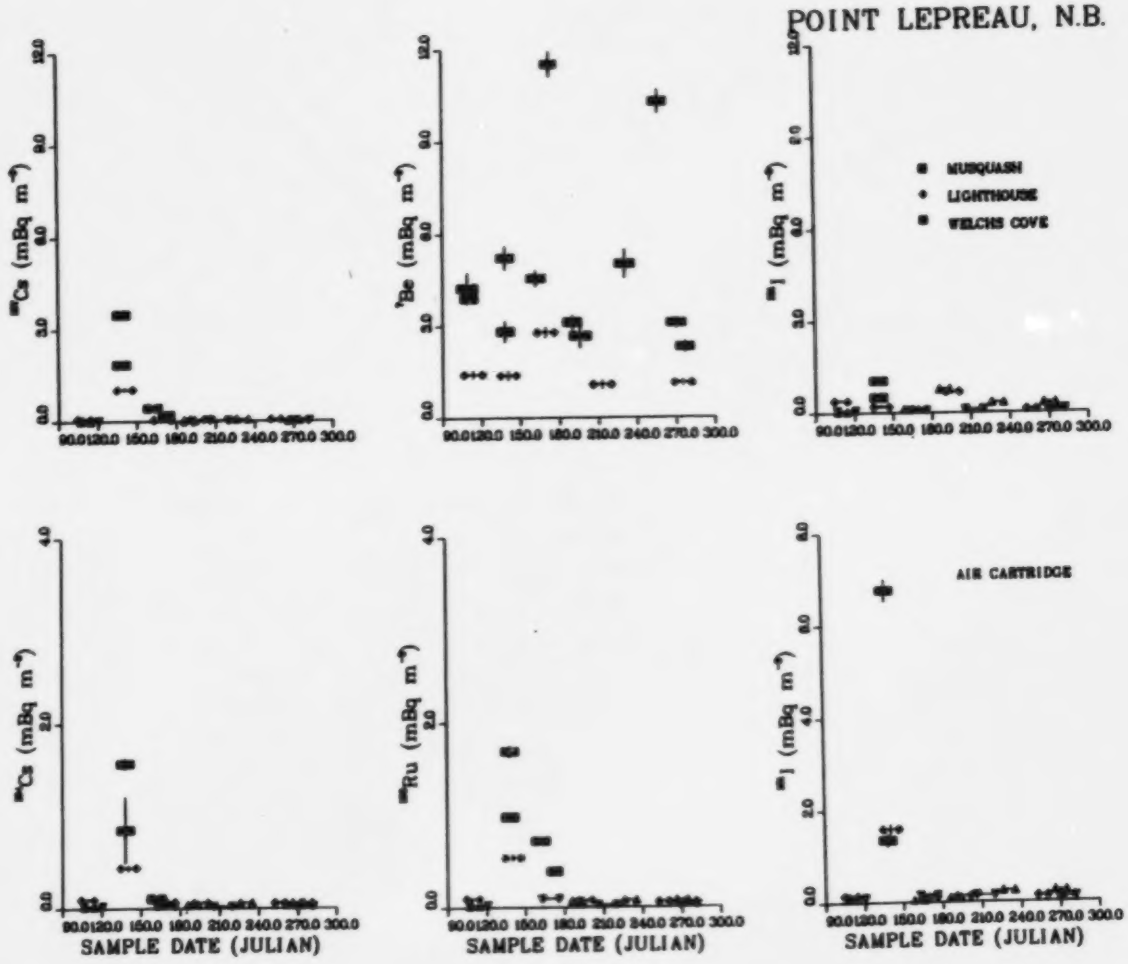


Figure 43. Air particulate activities at Station 1 (Musquash), Station 3 (Point Lepreau Lighthouse) and Station 4 (Welch's Cove) from April 30 (Julian day 120) to June 29 (Julian day 180), 1986. Δ signifies the activity is less than the value illustrated for station 1, ∇ for station 3 and for station 4. I 131 activity on air charcoal cartridge is also included.

Table 29: Radionuclide activities (mBq/m$^3$) in air at Dipper Harbour, N.B., 1986.

| Sample Period | Be-7 | Cs-137 | Cs-134 | I-131 | | Ru-103 | Other |
|---|---|---|---|---|---|---|---|
| | | | | Particulate | Gaseous | | |
| May 4-5 | <2.1 | <0.27 | <0.31 | <0.36 | <0.49 | <0.25 | |
| 5-6 | <1.7 | <0.15 | <0.15 | <2.00 | <1.21 | <0.22 | |
| 6-7 | <2.3 | <0.65 | <0.25 | <0.26 | <0.88 | <0.27 | |
| 7-8 | <1.6 | <0.22 | <0.19 | <0.27 | <0.48 | <0.24 | |
| 8-9 | <3.6 | <0.45 | <0.40 | 3.09±0.37 | 6.0±2.0 | <0.40 | |
| 9-12 | 3.21±.64 | 3.81±0.11 | 1.54±.07 | 7.51±.17 | 13.9±0.8 | 0.63±.06 | Te-132 1.02±0.13<br>La-140 9.3±1.8<br>Cs-136 detected |
| 12-14 | 4.22±.63 | 3.16±.13 | 1.41±.09 | 5.99±.19 | 8.05±1.30 | 0.53±.07 | |
| 14-16 | 3.06±.57 | 2.71±.11 | 1.14±.08 | 3.49±.13 | 6.10±.80 | 0.65±.07 | La-140 detected |
| 16-19 | <0.82 | 0.76±.06 | 0.13±.05 | 0.31±.07 | 2.15±.50 | 0.57±.05 | |
| 19-21 | <1.70 | <0.22 | <0.19 | <0.28 | 1.40±.45 | <0.20 | |
| 21-23 | <1.10 | 0.35±.07 | <0.13 | <0.22 | <0.30 | 0.38±.07 | |
| 23-26 | 1.27±.26 | 0.38±.04 | 0.20±.05 | 0.30±.05 | 1.30±.50 | 0.54±.04 | |
| 26-28 | 1.92±.54 | 0.73±.09 | 0.09±.07 | <0.23 | <0.38 | 0.96±.08 | |
| 28-30 | 1.94±.54 | 0.53±.08 | 0.26±.06 | <0.23 | <0.34 | 0.70±.08 | |
| May 30-June 2 | 4.66±.50 | 0.99±.07 | 0.30±.05 | <0.58 | <0.72 | 1.33±.08 | |
| June 2-4 | 4.40±.50 | 1.82±.09 | 0.62±.07 | 0.61±.11 | <0.47 | 2.83±.10 | |
| 4-6 | 8.55±.61 | 1.84±.09 | 0.65±.07 | 0.33±.10 | 0.80±.90 | 3.11±.10 | |
| 23-25 | 2.52±.54 | <0.15 | <0.14 | <0.24 | <1.2 | <0.14 | |
| 25-27 | 3.66±.49 | <0.12 | <0.11 | <0.20 | <0.35 | <0.12 | |
| 27-29 | 2.48±.41 | <0.14 | <0.15 | <0.41 | <0.40 | <0.16 | |

Table 30. Radionuclide activities (mBq/$m^3$) in air at Digby, N.S., in 1986.

| Sample Period | Be-7 | Cs-137 | Cs-134 | I-131 | | Ru-103 | Other |
|---|---|---|---|---|---|---|---|
| | | | | Particulate | Gaseous | | |
| May 3-4 | 3.15±.89 | <0.25 | <0.29 | <0.26 | <0.38 | <0.23 | |
| 4-5 | 4.60±.81 | <0.24 | <0.28 | <0.26 | <0.37 | <0.20 | |
| 5-7 | 1.99±.44 | <0.12 | <0.13 | <0.12 | <0.19 | <0.11 | |
| 7.9 | 3.1±.5 | 0.41±.08 | 0.15±.08 | 1.93±.12 | 2.62±.16 | 0.12±.06 | Te-132 0.12±.06 |
| 9-11 | 7.3±1.0 | 6.3±.2 | 2.82±.12 | 11.88±.23 | 19.90±.58 | 1.03±.09 | Te-132 1.49±.11 |
| | | | | | | | I-132 detected |
| | | | | | | | La-140 1.95±.36 |
| 11-13 | 2.54±.48 | 1.47±.09 | 0.49±.07 | 3.99±.13 | 7.40±.41 | 0.40±.06 | Te-132 0.31±.09 |
| 13-15 | 6.48±.67 | 4.88±.19 | 2.14±.11 | 7.59±.20 | 8.44±.25 | 1.24±.09 | Te-132 0.60±.12 |
| | | | | | | | La-140 3.39±.74 |
| 15-17 | 3.77±.54 | 3.05±.12 | 1.22±.09 | 2.96±.13 | 6.21±.28 | 1.43±.08 | Cs-136 0.43±.10 |
| 17-19 | <0.10 | 0.67±.07 | 0.31±.05 | <0.17 | 2.34±.23 | 0.56±.06 | |
| 19-21 | 1.28±.50 | 0.56±.07 | 0.13±.03 | <0.17 | 1.51±.17 | 0.81±.06 | |
| 21-23 | 4.37±.52 | 1.57±.10 | 0.54±.09 | 0.48±.08 | 1.65±.22 | 1.32±.08 | |
| 23-25 | <0.81 | <0.11 | <0.10 | <0.13 | 0.88±.21 | <0.10 | |
| 25-27 | 2.36±.52 | 1.05±.09 | 0.31±.05 | 0.48±.10 | 1.42±.25 | 1.21±.08 | |
| 27-29 | 2.05±.54 | 1.11±.09 | 0.31±.07 | 0.41±.10 | 1.49±.23 | 1.14±.09 | |
| May 29-June 2 | 4.07± 28 | 0.57±.04 | 0.17±.03 | 0.44±.05 | 1.86±.24 | 1.08±.05 | |
| June 2-4 | 3.09±.79 | 1.13±.13 | 0.36±.10 | 0.57±.13 | 1.17±.18 | 1.77±.13 | |
| 4-6 | 7.88±.46 | 1.44±.07 | 0 38±.05 | 0.41±.08 | 0.74±.09 | 2.29±.07 | |
| 18-20 | 3.23±.70 | <0.17 | <0.15 | <0.26 | <0.27 | <0.17 | |
| 20-22 | 4.88±.48 | <0.11 | <0.10 | <0.20 | <0.32 | <0.11 | |
| 22-25 | 2.85±.64 | <0.14 | <0.13 | <0.26 | <0.21 | <0.14 | |
| 25-27 | 2.20±.75 | <0.19 | <0.17 | <0.32 | <0.14 | <0.18 | |

Cove, N.B.) are illustrated for the time period of March 30 (Julian day 90) to Oct. 27 (Julian day 300) in Figure 43. The data is listed in Table 14.

The distributions of Chernobyl fallout in air in Digby and Dipper Harbour are similar to those measured in areas by the Environmental Health Directorate (1987, Figure 44) and by New Brunswick Electric Power Corporation (NBEPC, 1987). A comparison of the Cs-137 air particulate concentrations for Digby, N.S. (AERU) and Digby, Greenwood and Halifax, N.S. (Health and Welfare, 1987) and for Cs-137 at Dipper Harbour, N.B. (AERU and Site 1, NBEPC, 1987) are given in Figure 44.

### Be-7

Although the time dependencies of the fallout nuclide signals are similar for Dipper Harbour and Digby, absolute levels measured at Dipper Harbour are consistently lower for all nuclides, including naturally produced Be-7. The air concentrations of particle-associated radionuclides depend on the source function, including the particle load and meteorological conditions which govern aerial transport. Beryllium-7, a short-lived ($t_{\frac{1}{2}}=53$ d), particle-associated radionuclide of cosmic origin has been widely used as a tracer of atmospheric mixing (Lal and Peters, 1967). Some variation in Be-7 activity is apparent but activities fluctuated around an average activity of 3.0 mBq/m$^3$ for 1986 (Section 3.2.2.1). Normalizing radionuclide particulate activities to those of particulate Be-7 compensates for differences in atmospheric particulate load. The temporal distribution pattern of the fallout products in air is modified, and between the sets of data from the two different locations are largely eliminated. The increase in fallout radionuclides observed June 2 to 6 (Figures 41 and 42) occurs at a time when Be-7 activities also peak. After normalizing the air activities to their corresponding Be-7 activity, as shown for I-131 in Figure 45, for Cs-134 in Figure 46 and for Ru-103 in Figure 47, the peaks are eliminated. This indicates that this peak is an artifact caused by an increase in air particulate concentrations and does not represent a different air mass or component of the Chernobyl fallout plume. Good agreement of ratios between fallout

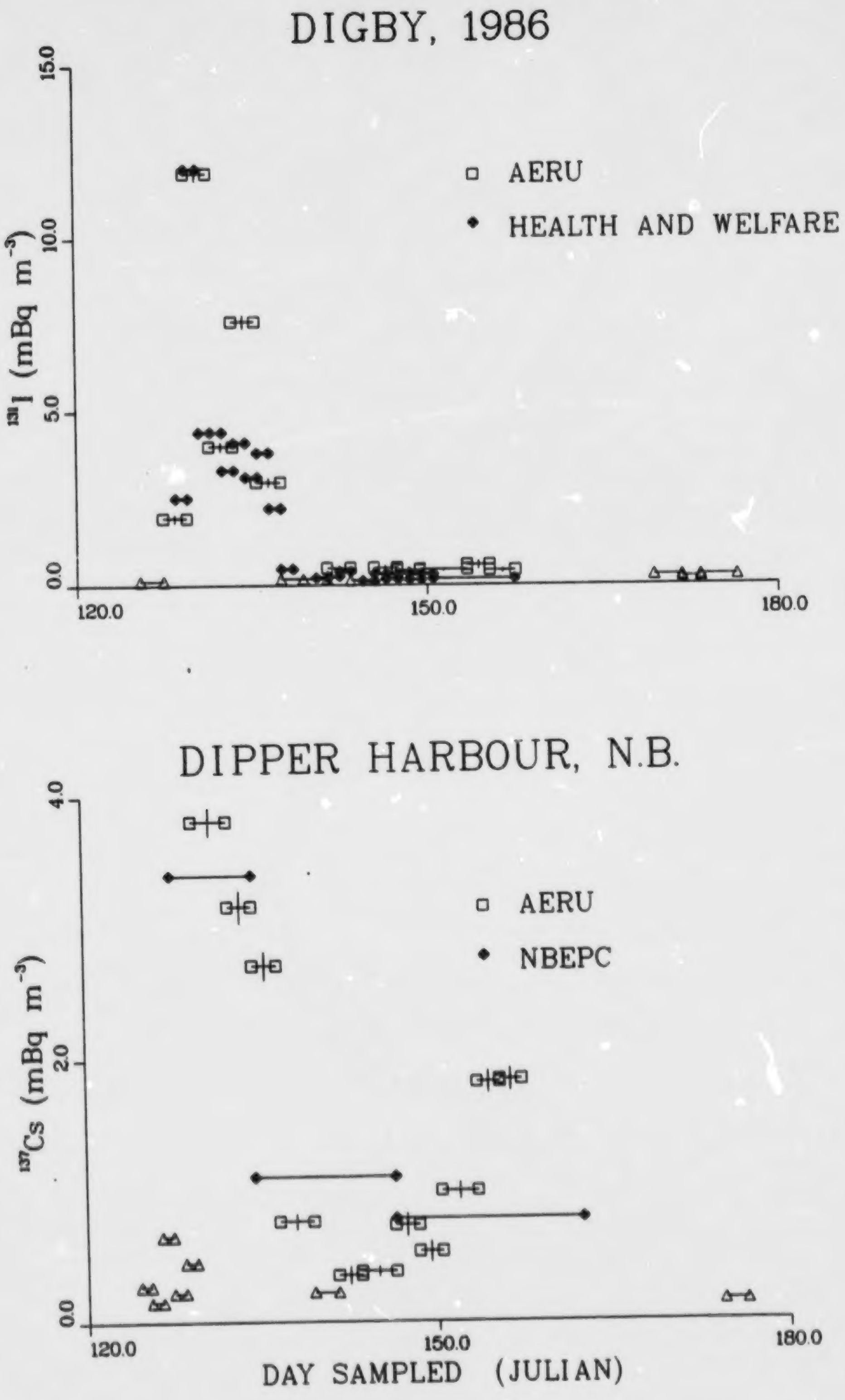


**Figure 44.** Intercomparison of air particulate data. The top figure gives the comparison of I-131 air particulate activities measured by AERU at Digby, N.S., to that measured by HWC (1987) at Digby, Greenwood and Halifax, N.S., from the period May 30 (Julian day 120) to June 29 (Julian day 180), 1986. Bottom figure gives the comparison of Cs-137 activities (AERU) to those of NBEPC at Dipper Harbour, N.B.

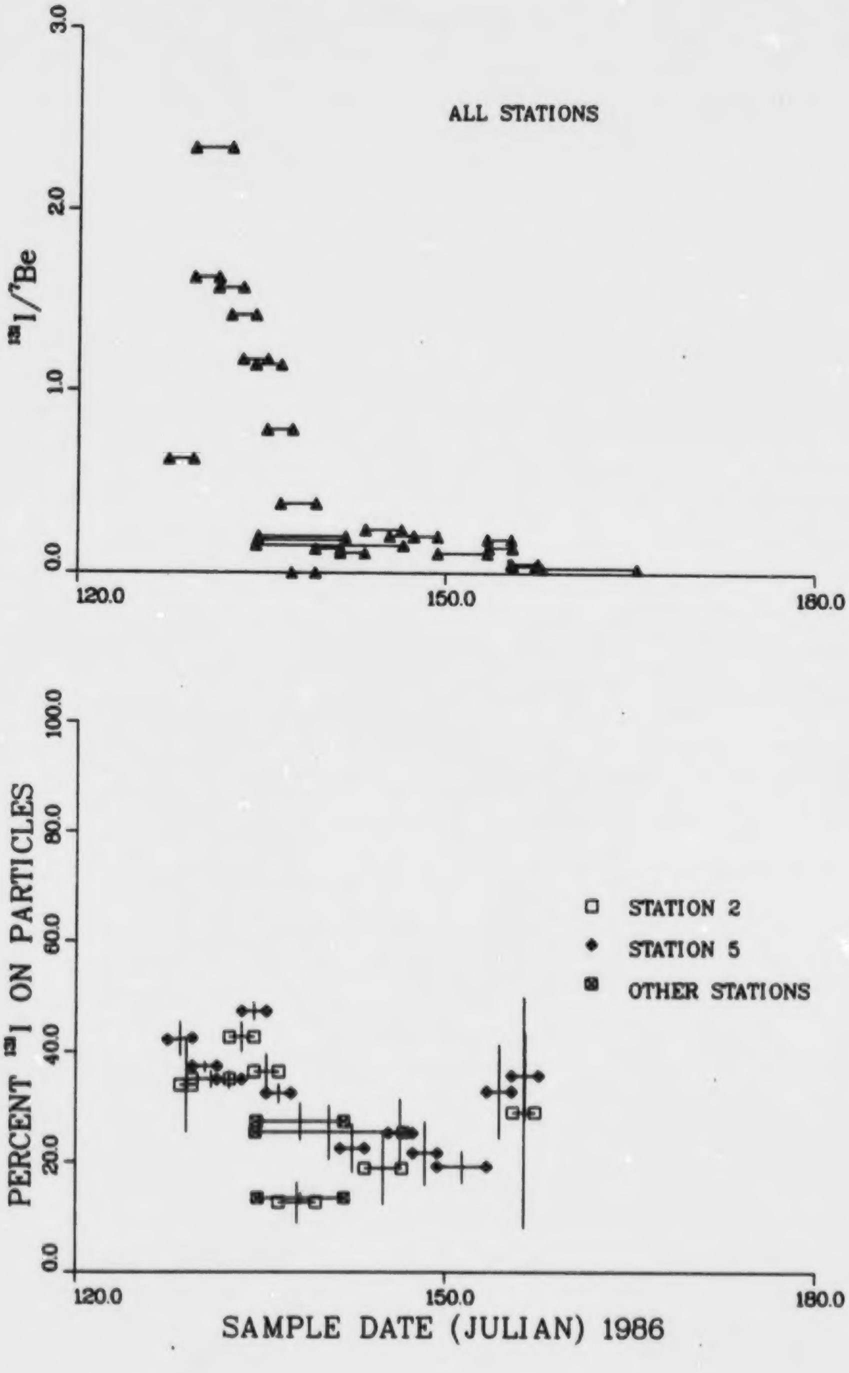


Figure 45. I-131 in air. The top figure gives the particulate I-131 activity normalized to the Be-7 activity from April 30 (Julian day 120) to June 29 (Julian day 180), 1986. The distrbution of I-131 on particles is shown for all the stations during the same time period in the bottom figure.

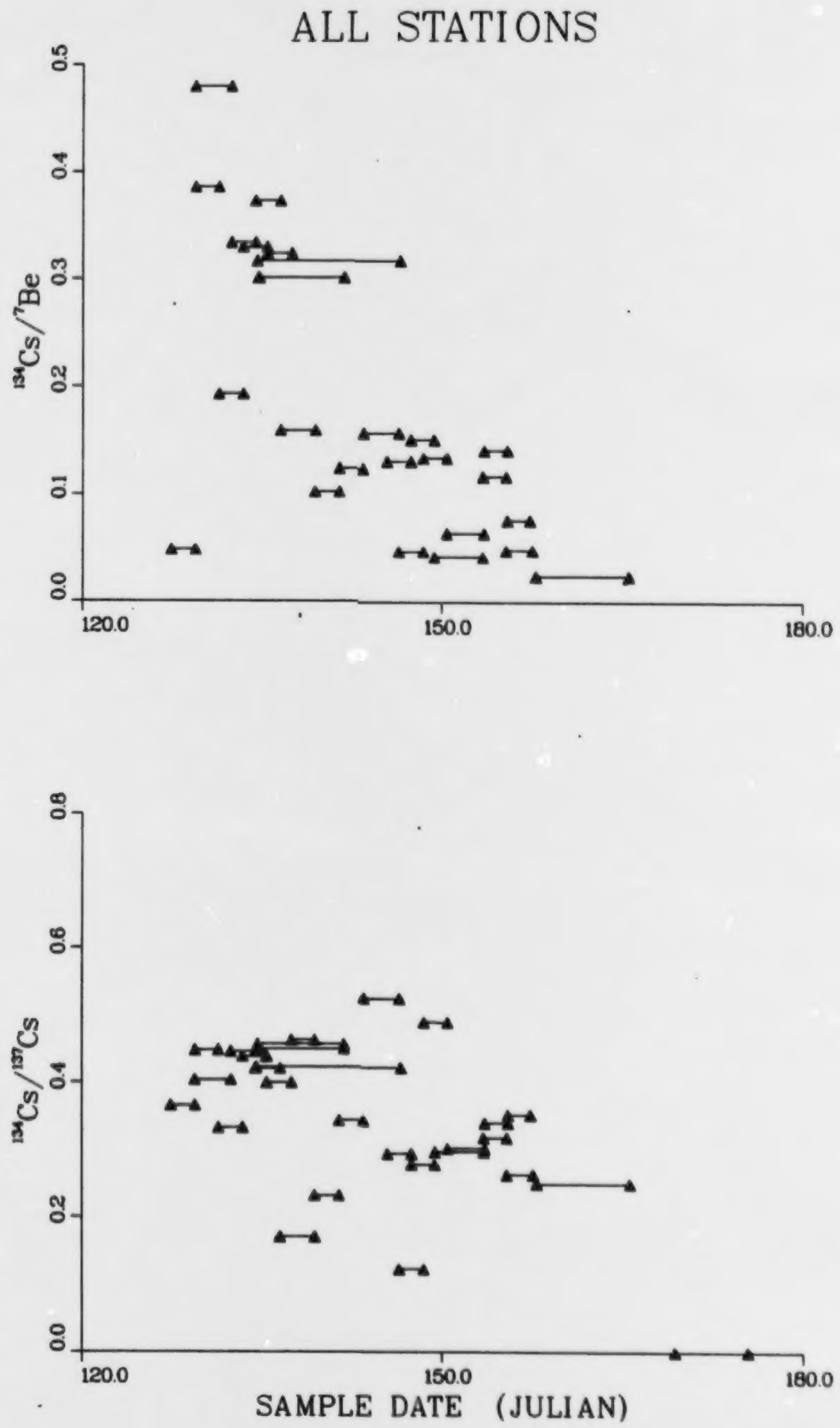


**Figure 46.** Cs-134 in air. Top figure gives the particulate Cs-134 activity normalized to the Be-7 activity from April 30 (Julian day 120) to June 29 (Julian day 180), 1986. The Cs-134/Cs-137 ratio in air is shown for the same time period in the lower figure. The initial ratio for Chernobyl releases was 0.5.

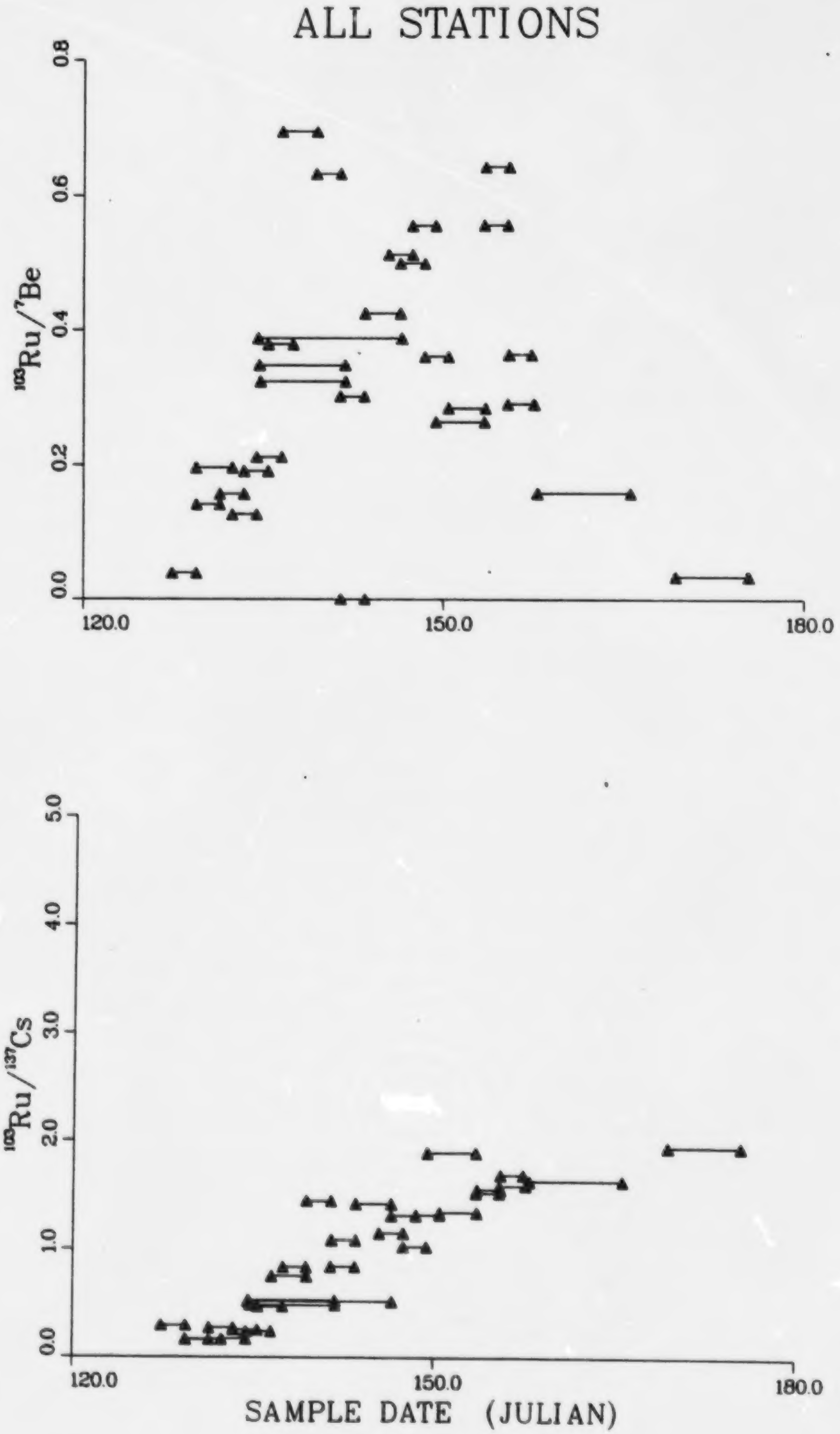


**Figure 47.** Ru-103 in air. The top figure gives the particulate Ru-103 activity normalized to the Be-7 activity from April 30 (Julian day 120) to June 29 (Julian day 180), 1986. the Ru-103/Cs-137 ratio in air is shown for the same time period in the lower figure.

radionuclide activities to Be-7 activities for various locations is also evident despite the fact that the absolute activities vary considerably at each location although the greater atmospheric particulate concentrations at Digby yield larger absolute inventories of Chernobyl radionuclides compared to those at Dipper Harbour.

## I-131

Iodine-131 was the chief contributor to the fallout radioactivity from Chernobyl and is one of the major concerns regarding radiation doses in humans due to the ability of iodine to concentrate in the thyroid gland (Fry *et al.* 1986). Iodine was initially injected into the atmosphere in the gaseous form (Aoyama *et al.* 1986) and was slowly absorbed onto particles.

The nuclide was measured in eastern Canada both on activated charcoal (gaseous form) and on filters (particulate form). The maximum level of total I-131 (gaseous + particulate) was 31.8 mBq/m$^3$, measured at Digby, N.S. on May 9-11. This was by far the highest air activity measured for any nuclide at either location, although the activity is 1000 times lower than the maximum levels of I-131 measured in Sweden when the plume initially arrived there (Devell *et al.* 1986).

The fractionation between the particulate and gaseous phase iodine is given in Figure 45 for all stations. Between 20 and 50% of the total I-131 atmospheric inventory was associated with particles. The initial particulate percentage of 40-45% in early May decreased to 20% by the end of May, but increased again June 4-6. When the Chernobyl plume was initially measured in Sweden, 70-80% of the I-131 was found to be in the gaseous form in samples (Devell *et at.* 1986). By May 6, the gaseous form was still dominant. In Japan, 75-80% of the I-131 was found to be in the gaseous form on May 5-6, decreasing to 65% over the next 10 days (Aoyama *et al.* 1986). The gaseous form was found to be >40% in North America (Tennessee) when the plume arrived on May 7-16 (Bondietti & Brantley, 1986), indicating that little transfer from the gaseous form to the particulate form occurred during the transit time from Europe to North America. Results at Digby and Point Lepreau agree well with those for Europe, Japan and the USA. The decrease in the fractional amount of particulate I-131 observed at both stations occurred on May 16-18 and is synchronous with other changes in the composition of the fallout, indicating that a significantly different component of the Chernobyl plume was transported into the area. This event is discussed below.

## Cesium-134 and Cesium-137

Because of the high volatility of cesium, its isotopes Cs-134 ($t_{\frac{1}{2}} = 2.07y$) and Cs-137 ($t_{\frac{1}{2}} = 30.2y$) were among the first nuclides to be detected and were readily observed until mid-June. The time dependence of both isotopes similar at Digby and Dipper Harbour to that of I-131. The activities of Cs-137 and Cs-134 decreased more slowly following their peak concentrations compared to I-131 due to the longer half-lives of the cesium isotopes. As was the case for I-131, normalization of the cesium isotope activities to Be-7 improves the agreement between the Digby and Dipper Harbour results as illustrated in Figure 46 for Cs-134/Be-7.

Ratios of Cs-134/Cs-137 at Point Lepreau decreased from values of 0.45 beginning May 16 to 0.3 by mid-June (Figure 46). The decrease reflects both the increased loss of Cs-134 to Cs-137 by the higher rate of radioactive decay and temporal changes in the source function. Measured ratios of Cs-134/Cs-137 of 0.5 in surface air in Sweden (Devell *et al.* 1986) were also measured both on airplane swipes on May 2-6 (Savadivan & Mishra, 1986) in Japan (Imanaka & Koide, 1986) and across the USA with little spatial or temporal variability (Larsen *et al.* 1986). These results are in good agreement with ratios measured in this study.

## Ru-103

Ruthenium-103 is a comparatively short-lived ($t_{\frac{1}{2}} = 39.6$ d) fission product which is present at levels similar to those of the cesium isotopes (Figures 41, 42, 43). Ruthenium is refactory and its presence alone establishes that very high temperatures accompanied the release of radioactivity from the damaged reactor. However, the chronology for Ru-103 transport through eastern Canada is significantly different compared to that of Cs-134 and Cs-137 and I-131, with maximized air concentrations of Ru-103 being delayed until early June. As in the case of Cs and I-131 agreement between stations is enhanced when the Ru-103 data is normalized to Be-7 (Figure 47). However, the air transport characteristics of Ru-103 are best illustrated in the Ru-103/Cs-137 ratio (Figure 47). This ratio remained relatively constant at 0.2 between May 7 (Julian day 127) and 16 (J.D. 136) during the time that the remaining radionuclide activities on air registered their maximum values and then declined. This is in good agreement with the Ru-103/Cs-137 activity ratio of 0.17 measured in the first Chernobyl emissions detected in Sweden on April 28-30 (Devell *et al.* 1986). However, beginning with samples collected May 16-18, simultaneous with the I-131 fractionation changes in air, the ratio increases in a linear manner attaining a constant value of 2.0 for samples collected at the end of June. This increase in the ratio is a result of an additional input of Ru-103 as evidenced by the increase in the Ru-103/Be-7 ratio at this time (Figure 47), and by the absence of a corresponding increase in the Cs-137/Be-7 ratio (Figure 46). Similar changes were noted in Tennessee (Bondietti and Brantley, 1986) although initial ratios of 0.66 were higher than those measured in eastern Canada (0.2). The changes in the Ru-103/Cs-137 ratio in the Chernobyl plume reflect temporal changes in the release rate of radioactivity from the damaged reactor and the arrival of different air masses in eastern Canada. The later enhanced activities of Ru-103 are probably the result of inputs from a new air mass containing delayed releases from the reactor characterized by higher activities of the less volatile elements and lower activities of the more volatile ones. Other radionuclides of less volatile elements, such as Ru-106, Ce-141, Ce-144, Zr-95 and Nb-95, were detected at other locations such as Sweden (Devell *et al.* 1986), the United Kingdom (Fry *et al.* 1986), Hungary (Csongor *et al.* 1986), on swipes from airplanes passing between India and the USA (Savadivan & Mishra, 1986) and in Japan (Imanaka & Koide, 1986).

### 7.2.3 Rainfall Results

The principal transport pathways for biological uptake of airborne radionuclides are by direct exposure of organisms to particulate and gaseous radionuclides and by exposure to radionuclides deposited by wet and dry precipitation onto the ground or onto the surface of organisms. Rainfall is very effective at removing radionuclides from the atmosphere and several periods of rainfall occurred in eastern Canada as the Chernobyl plume passed through the region. Results for the rainwater samples collected in the Halifax area are given in Table 31. Generally, I-131 was the only fallout product measured in rainwater with the exception of Ru-103 and Te-132 which were measured in the first sample only. The first storm occurred on May 11, one day after maximum levels of radionuclides were attained in air. Maximum levels of I-131 measured at the beginning of this storm were 81 mBq/ℓ. Iodine-131 levels decreased substantially throughout the storm (Figure 48) as most of the activity was stripped from the atmosphere at the beginning of the storm. During the second period of precipitation on May 12-13, levels of I-131 were lower but still decreased throughout the storm period. Levels of I-131 were much lower in rainwater during the subsequent periods of precipitation on May 17 and 23.

## 7.3 Biological Oceanography

Various marine biological samples were collected in the Point Lepreau area in August, 1986 and samples of marine algae were collected near Halifax at Herring Cove and at Portuguese Cove during May, June and July. Algae samples collected in the Halifax area were analyzed in wet form for the gamma-emitting nuclides in the same manner as was described previously (Section 4.2).

Results for the gamma analyses of samples collected in the Halifax area are given in Table 32. Radionuclide levels given in Bq/wet weight can be converted to Bq/dry weight by multiplying by 25. Iodine-131 was readily measured in all samples collected, despite the diluting effect of the ocean. Maximum levels of 29 Bq/kg wet weight (approximately

Table 31. Radionuclide activities (mBq/ℓ) in rain at Halifax, N.S., 1986.

| Sample Date | | Location | I-131 | Cs-137 | Be-7 | Other |
|---|---|---|---|---|---|---|
| Midpoint | Duration | | | | | |
| 11 May 18:00 | 30 min. | Herring Cove | 81.0±1.2 | <0.3 | 15.9±1.5 | Ru-103 1.8±0.2, Te-132 0.9±0.3 |
| 11 May 22:00 | 5 min. | Lower Sackville | 24.4±1.0 | <0.6 | <5.5 | |
| 11 May 22:00 | 2 hr. | Halifax | 17.9±0.9 | <0.6 | <5.3 | |
| 12 May 03:00 | 8 hr. | Cole Harbour | 36.2±1.0 | 0.7±0.5 | <5.6 | |
| 12 May 10:05 | 10 min. | Dartmouth | 12.4±0.7 | 0.3±0.3 | <4.6 | |
| 13 May 03:30 | 11 hr. | Hacketts Cove | 9.3±0.7 | <0.6 | <5.0 | |
| 17 May 12:10 | 1 min. | Halifax | 3.15±0.62 | <0.5 | <4.7 | |
| 17 May 12:30 | 1 min. | Cole Harbour | 2.34±0.23 | <0.24 | <2.1 | |
| 17 May 13:45 | 1 min. | Halifax | 2.83±0.54 | <0.64 | <4.8 | |
| 17 May 14:12 | 1 min | Cole Harbour | <0.83 | <0.60 | <4.8 | |
| 17 May 15:45 | 1 min. | Cole Harbour | 3.13±0.63 | <0.61 | <5.6 | |
| 17 May 16:05 | 1 min. | Halifax | 4.81±0.82 | <0.84 | <6.7 | |
| 17 May 18:08 | 1 min. | Cole Harbour | 3.15±0.74 | <0.66 | <5.9 | |
| 17 May 22:15 | 1 min. | Cole Harbour | 0.67±0.22 | <0.23 | <1.8 | |
| 23 May 07:05 | 1 min. | Cole Harbour | 3.16±0.49 | <0.26 | <4.2 | |
| 25 May 08:20 | 1 min. | Timberlea | 0.92±0.37 | <0.69 | <4.8 | |
| 2 June 13:15 | 1 min. | Dartmouth | <0.24 | 0.62±0.16 | 6.1±1.2 | |
| 8 June 11:00 | 1 min. | Herring Cove | <0.59 | <0.32 | <2.0 | |

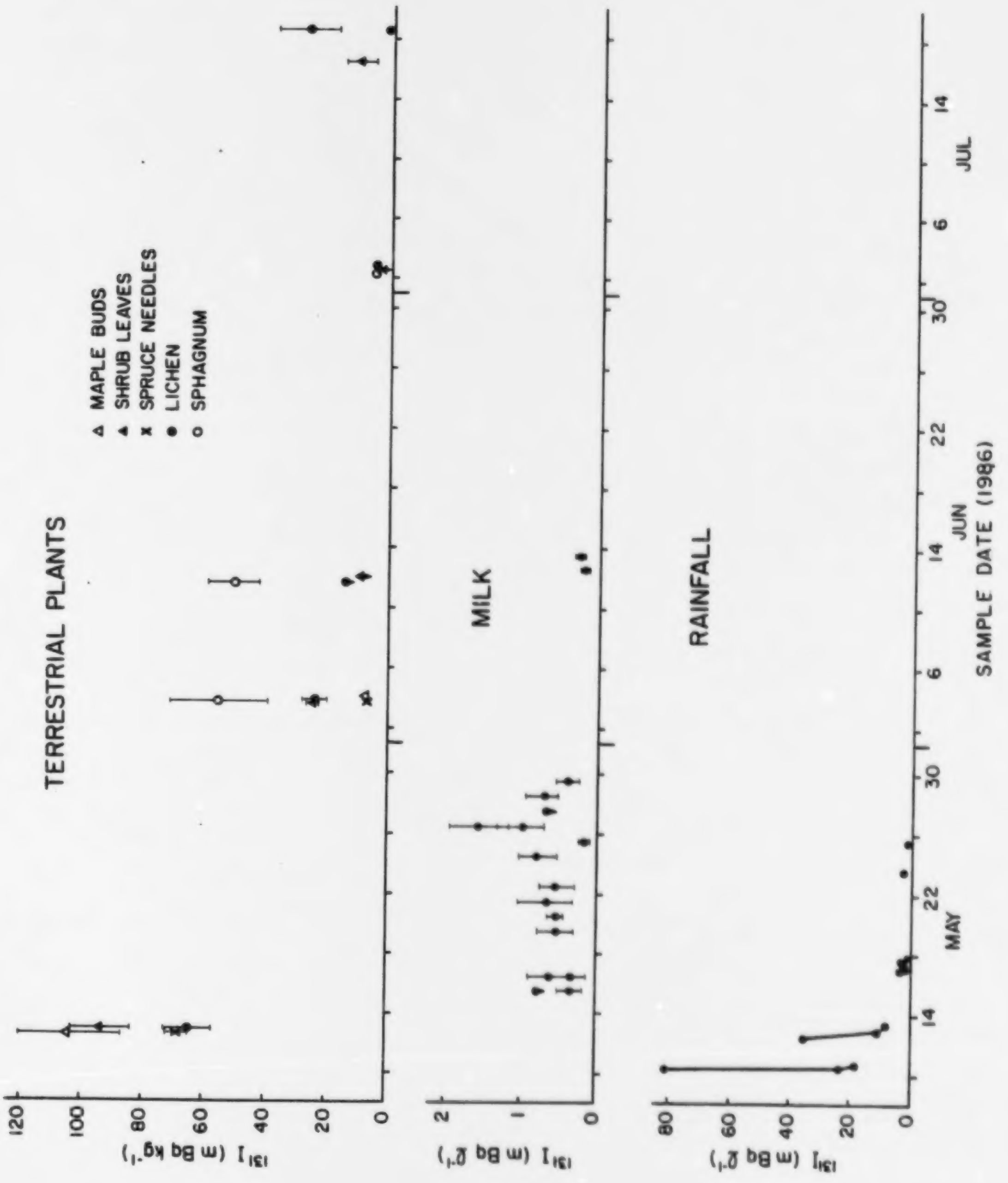


Figure 48. I-131 in rainfall (Halifax), I-131 in milk (Truro), and I-131 in terrestrial plants (BIO).

Table 32. Radionuclide levels in algae in the Halifax area, 1986.

| Sample # | Sample date | Location | Species | I-131 Bq/kg (wet) | Cs-137 Bq/kg (wet) | Ru-103 Bq/kg (wet) | Be-7 Bq/kg (wet) | Other Bq/kg (wet) |
|---|---|---|---|---|---|---|---|---|
| 13520 | May 15 | Herring Cove | Dulse | 2.4±0.3 | <0.4 | | | |
| 13521 | May 15 | Portuguese Cove | Ascophyllum | 9.4±0.4 | <0.4 | | | |
| 13551 | May 29 | Herring Cove | Laminaria | 29.1±1.8 | <1.3 | | | |
| 13552 | May 29 | Herring Cove | Ascophyllum | 11.5±0.6 | <0.5 | 1.27±0.25 | | |
| 13553 | May 29 | Herring Cove | Rhodymenia | 1.6±0.4 | <0.7 | 1.46±0.25 | | |
| 13569 | June 13 | Portuguese Cove | Ascophyllum | 2.6±0.2 | <0.5 | 1.54±0.23 | | |
| 13570 | June 13 | Portuguese Cove | Fucus | 2.3±0.3 | 1.37±0.29 | 2.46±0.30 | 11.2±2.2 | Co-60 1.2±0.4 |
| 13571 | June 13 | Herring Cove | Dulse | 1.9±0.3 | <0.9 | | | |
| 13572 | June 13 | Herring Cove | Ascophyllum | 4.1±0.3 | <0.4 | 0.76±0.18 | 5.6±1.4 | |
| 13573 | June 13 | Herring Cove | Fucus | 3.0±0.4 | 0.76±0.22 | 2.21±0.30 | | |
| 13574 | July 7 | Herring Cove | Fucus | 2.3±0.3 | <0.4 | | | |

0.7 mBq/kg dry weight) were measured in Laminaria on May 29. The brown algae - fucus, laminaria and ascophyllum - were always higher than the red algae species (*Chondrus crispis*) by a factor of 2-10. This is in agreement with Bowen (1979) who determined concentration factors for elemental iodine to be much higher in brown algae (CF = 300 for red algae and 5000 for brown algae). Cesium-137 was detected in samples collected in June 13, but levels are very close to the detection limit, similar to pre-operational, pre-Chernobyl levels of Cs-137 in algae of 0.3-2.0 mBq/kg dry weight (Ellis *et al.* 1984, Section 4.3). Ruthenium-103 was measured in most algae samples after May 29. This is consistent with delayed inputs from the atmosphere of this less volatile radionuclide relative to I-131 and cesium isotopes. Of interest is the one sample of fucus collected on June 13 in which Co-60 was detected. No Cs-134 was measured in any sample.

Samples were collected at Point Lepreau in August, several months after the Chernobyl fallout reached the east coast of Canada, when atmospheric radionuclide levels were greatly reduced. No I-131 was measured in environmental samples (Table 17). Cesium-137 levels measured (0.3-1.5 Bq/kg dry weight) are in the range of pre-operational levels. One sample of laminaria contained measurable levels of Cs-134. The Cs-134/Cs-137 ratio for this sample of 2.2 ± 1.5 provides little additional information due to the large uncertainties associated with the ratio. One clam sample collected on August 15, contained a measurable level of Cs-134 (0.3 ± 0.2 Bq/kg) (Table 18). The Cs-134/Cs-137 ratio of 0.6 was in good agreement with the fallout ratio.

## 7.4 Terrestrial Environment

Terrestrial samples were collected in the Halifax, N.S. area at the Bedford Institute of Oceanography (BIO) property and in the Point Lepreau area at the standard sampling locations of PLEMP. In addition, milk samples were collected prior to pasturization from Baxter Dairies of Truro, N.S. were analyzed through May and June. Samples of rhubarb and canned mushrooms were also analyzed at the request of the RPB.

### 7.4.1 Milk

Contaminated milk is a major potential source of fallout radionuclide products to humans. Grazing cattle consume large quantities of radioactivity deposited on grass and uptake of radioisotopes, especially I-131, Cs-137 and Cs-134, occurs rapidly in their milk.

Samples of milk collected from May 15 to May 30 were analyzed for I-131, Cs-137 and Cs-134 at BIO at the request of Health and Welfare Canada as part of their health monitoring program. Two additional samples were collected on June 12 and 13. The samples of milk were a mixture of various unpasturized farm milks, collected at the Baxter Dairies Limited in Truro, N.S. The results of these analyses are given in Table 33. The distribution of I-131 in milk is illustrated in Figure 48. Iodine-131 was measured in the first sample at a level of 0.34 Bq/1. The concentrations of I-131 gradually increased to a maximum level of 1.57 Bq/1, measured on May 26 and then decreased to 0.3 Bq/1 in the final sample collected on June 13. Levels were well below the Canadian federal standard for the maximum permissable concentration of I-131 in drinking water of 10 Bq/1.

Samples of milk collected in Fredericton, N.B., exhibited similar levels of I-131, ranging from 0.2 to 1.1 Bq/1 (NBEPC, 1987). Iodine levels in milk collected in Ottawa during the same period were slightly lower than those measured in Nova Scotia and New Brunswick, ranging from 0.1 to 0.4 Bq/1 (Environmental Health Directorate, 1987).

Cesium-137 and Cs-134 were below the detection limit in the milk samples collected in May, although Cs-137 and Cs-134 were detected at low levels in the two milk samples collected in June. The Cs-134/Cs-137 ratio of 0.47 measured on June 12 is in agreement with the atmospheric ratio measured in eastern Canada in May.

The maximum level for I-131 in milk in Nova Scotia was measured on May 26, two weeks after air and rainfall concentration peaked in the same area (Figures 40, 42 and 48). The maximum I-131 level in milk in Britain was detected on May 6 (Fry *et al.* 1986), four days after the maximum air concentrations were attained. This delay was consistent with that

Table 33. Radionuclides in milk, 1986.

| Sample Date | I-131 | Cs-137 Bq/ℓ | Cs-134 Bq/ℓ |
|---|---|---|---|
| May 15 | 0.34 ±0.16 | <0.24 | <0.22 |
| May 16 | 0.36±0.24 | <0.73 | <0.67 |
| May 16 | 0.61±0.27 | <0.82 | <0.82 |
| May 19 | 0.53±0.25 | <0.70 | <0.74 |
| May 20 | 0.53±0.08 | <0.27 | <0.27 |
| May 21 | 0.69±0.36 | <0.96 | <0.83 |
| May 22 | 0.55±0.19 | <0.60 | <0.57 |
| May 24 | 0.80±0.27 | <0.63 | <0.62 |
| May 25 | 0.18±0.08 | <0.25 | <0.21 |
| May 26 | 1.57±0.39 | <0.39 | <0.47 |
| May 26 | 1.02±0.31 | <0.83 | <0.67 |
| May 27 | 0.14±0.22 | <0.74 | <0.71 |
| May 28 | 0.69±0.17 | <0.53 | <0.47 |
| May 29 | 0.40±0.17 | <0.61 | <0.57 |
| June 12 | 0.20±0.06 | 0.43±0.10 | 0.20±0.07 |
| June 13 | 0.28±0.07 | 0.40±0.08 | 0.06±0.07 |

expected for transfer coefficients for I-131 from air to grass to milk of two to three days (Coughtrey *et al.* 1983). The larger delays observed in Nova Scotia were a result of the grazing pattern of the cattle. As a result of a cold and wet spring, the cattle were kept inside the barn, feeding on a mixture of old and freshly cut feed through the early part of May when Chernobyl inputs were maximized. After mid-May, the cattle grazed outdoors, feeding exclusively on fresh feed, leading to a maximum in the I-131 milk level on May 26.

### 7.4.2 Plants

Samples of lichen, spruce needles, shrub leaves, sphagnum and maple buds were collected near BIO throughout the summer and results for gamma-emitting nuclides are given in Table 34. The samples generally contained measurable levels of I-131, Cs-137, Cs-134 and Ru-103 with activities of I-131 and Cs-137 being the highest. The highest level of I-131 was 104 Bq/kg measured in maple buds while the maximum concentration of Cs-137 was 140 Bq/kg measured in maple buds collected on June 3 and in sphagnum collected on July 2. Although no I-131 was measured on samples collected at Point Lepreau for PLEMP on July 5, some Cs-134, Cs-137 and Ru-103 was measured in lichen and several other samples (Table 23).

### I-131

The activities of I-131 in the plants collected at BIO are shown as a function of time in Figure 48 together with rainwater and milk results. Initial activities are highest in rapidly growing, new plants. The I-131 level in these plants decreased quickly to values below the detection limit by June 11. The overall removal rate, ($\lambda_{eff}$), the effective half-life for removal, ($t_{eff}$), and the biological half-life for removal, ($t_{biol}$) are determined using the following equations:

$$\ell n\, A(t) = -\lambda_{eff} t + \ell n\, A^{\circ} \qquad (3)$$

Table 34. Radionuclide results for terrestrial samples collected at B.I.O. in 1986.

| Sample # | Type | Sample Date | Be-7 Bq/kg | I-131 Bq/kg | Cs-137 Bq/kg | Cs-134 Bq/kg | Ru-103 Bq/kg | Cs-134/Cs-137 | Ru-103/Be-7 |
|---|---|---|---|---|---|---|---|---|---|
| 13509 | Spruce Needles | May 12 | 37±7 | 69±4 | 35±1 | - | 1.6±0.6 | - | .0432 |
| 13510 | Lichen | May 12 | 321±38 | 65±8 | 24±5 | <6 | <6 | <0.25 | <.0187 |
| 13511 | Alder Leaves | May 12 | <127 | 94±10 | <14 | -- | -- | -- | -- |
| 13512 | Maple Buds | May 12 | <85 | 104±17 | <21 | -- | -- | -- | -- |
| 13559 | Sphagnum | Jun 3 | 226±30 | 56±16 | 6635 | 14.4±3.9 | 24±5 | 0.218 | -- |
| 13560 | Spruce Needles | Jun 3 | 100±4 | 7.5±0.6 | 39±1 | 5.8±0.5 | 7.30±-.4 | 0.151 | -- |
| 13561 | Alder Leaves | Jun 3 | 122±9 | 25±2 | 53±2 | 6.08±1.0 | 14±1 | .133 | -- |
| 13562 | Lichen | Jun 3 | 629±27 | 24±4 | 101±3 | 25.0±2 | 43±3 | .248 | .0684 |
| 13563 | Maple Buds | Jun 3 | 93±9 | 8±1 | 140±2 | 1.1±0.2 | 6.4±0.9 | .008 | -- |
| 13564 | Spruce Needles | Jun 11 | <14 | <6.3 | 5831 | 3.1±0.8 | 5.8±0.9 | .054 | -- |
| 13565 | Sphagnum | Jun 11 | 437±31 | 51±9 | 9835 | 12.5±1.9 | 44±4 | 128 | -- |
| 13566 | Lichen | Jun 11 | 696±31 | 9±5 | 10834 | 33.7±3.1 | 37±3 | .312 | .0525 |
| 13867 | Alder Leaves | Jun 11 | 80±12 | <11 | 6532 | 4.7±1.6 | 14±2 | 0.72 | -- |
| 13586 | Spruce Needles | Jul 2 | 571±2 | <4 | 12233 | <3.3 | <2.8 | <.03 | -- |
| 13587 | Sphagnum | Jul 2 | 449±10 | 4.9±0.9 | 140±1 | 15.7±0.9 | 164±0.9 | .112 | -- |
| 13588 | Lichen | Jul2 | 429±19 | 4.7±1.6 | 83±3 | 22±2 | 17±2 | .265 | 0391 |
| 13589 | Spruce Needles | Jul 16 | 87±5 | <5 | 44±1 | 4.4±0.5 | 2.9±0.5 | .100 | -- |
| 13590 | Sphagnum | Jul 16 | 42 | <1 | 8±1 | <1 | <.1 | <.13 | -- |
| 13591 | Blueberry Leaves | Jul 16 | 762±30 | 11±4 | 50±1 | 40±3 | 27±3 | .800 | -- |
| 13592 | Lichen | Jul 18 | 664±33 | 28±10 | 242±7 | 22±3 | 94 | 091 | .0136 |
| 13593 | Lichen | Jul 18 | 312±6 | 11± | 256±3 | 14±1 | 81 | .055 | .0256 |
| 13594 | Lichen | Au 20 | 163±12 | <4 | 128±3 | 7±1 | 1.6±0.8 | .055 | .0123 |
| 13813 | Lichen | Aug 29 | 769±30 | <7 | 304±7 | 31±3 | 52 | 102 | 0065 |
| 13857 | Lichen | Sep 5 | 344±20 | <7 | 87±3 | 13±2 | 32 | 149 | 0087 |
| 13855 | Lichen | Sep 15 | 5561±6 | <3 | 113±2 | 18±1 | 2.11±.0 | .159 | .0036 |
| 13856 | Lichen | Oct 6 | 372±22 | <18 | 140±5 | 11±2 | <4 | .079 | <.011 |

$$t_{eff} = 0.693 / \lambda_{eff} \tag{4}$$

$$t_{eff} = \frac{t_{\frac{1}{2}}\, t_{biol}}{t_{\frac{1}{2}} + t_{biol}} \tag{5}$$

where A(t) and A° are the activities at times t and t = 0. These removal rates and half-lives can be estimated from the curves in Figure 49 where the logarithm of the I-131 activity is plotted against time for terrestrial plants. The effective half-life for each plant type is:

| | |
|---|---|
| spruce needles | 7 days |
| alder leaves | 11 days |
| maple buds | 6 days |
| sphagnum | 7 days |
| lichen | 11 days |

The removal rates of I-131 from these plants are similar. The average half-life for I-131 for all plants was calculated to be approximately 7.7 days, in good agreement with the radioactive half-life of I-131 (8.07 d). This corresponds to a slow rate of biological removal relative to the half-life of I-131 so that removal of I-131 from plants occurs predominantly by radioactive decay, as expected considering the short half-life of I-131. Iodine-131 is measured in lichen and sphagnum for a longer period of time, even though the removal rate is approximately the same, because these older and slower growing plants, known for their ability to collect material from the atmosphere, attain higher concentrations of I-131.

### Cs-134 and Cs-137

Residual levels of Cs-137 from nuclear tests in the atmosphere and soil contribute to the Cs-137 signal in plants making it more difficult to quantify the fallout component from Chernobyl. For example, the average level of Cs-137 measured for sphagnum in the summer of 1985 in the Point Lepreau vicinity was 62 Bq/kg (range of 7-123 Bq/kg) and was 34 Bq/kg for blueberry leaves (range of 4-66 Bq/kg) (Section 5.2.1). Although, the average values for

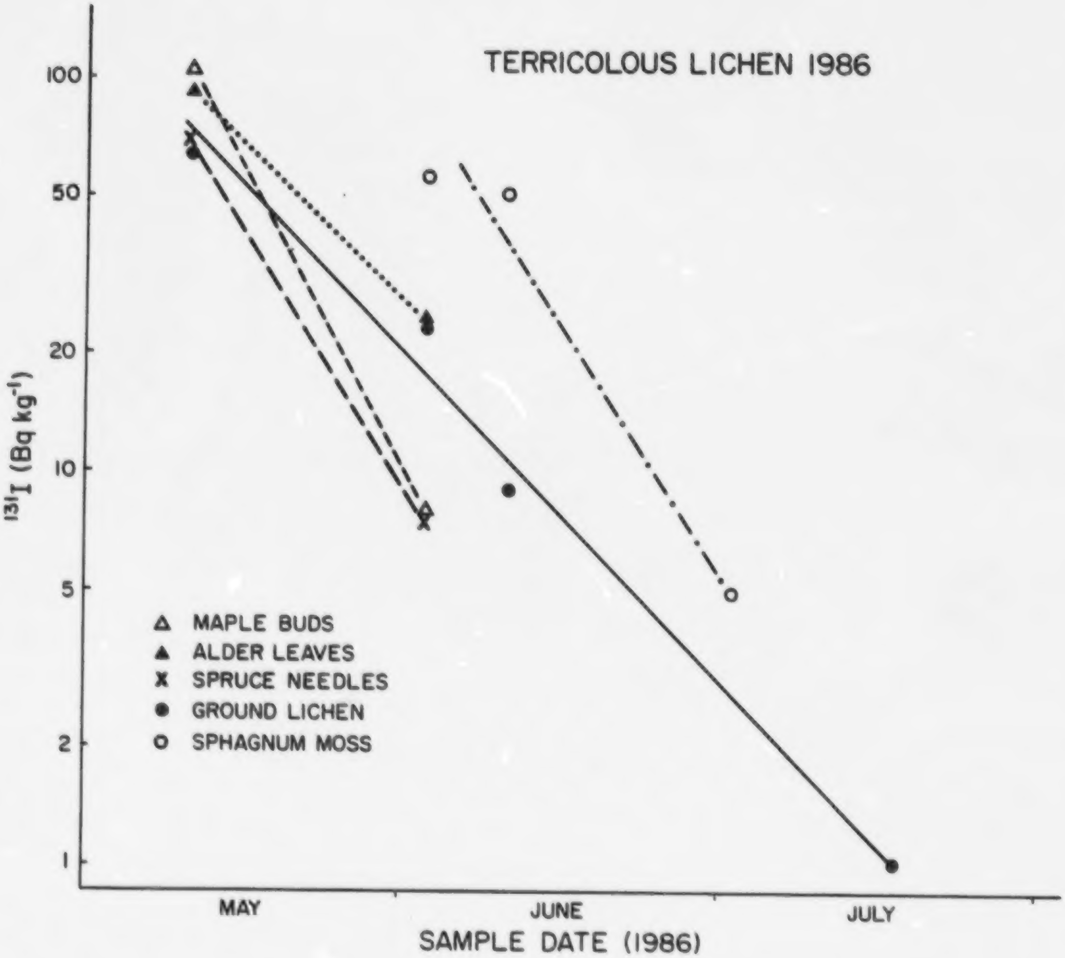


Figure 49. Log plot of I-131 in terrestrial plants.

1986, 154 Bq/kg for sphagnum (range of 100 to 224 Bq/kg) and 47 Bq/kg for blueberry leaves (range of 4 to 114 Bq/kg), were higher than in 1985, they were also within the range of pre-Chernobyl samples. Cesium-134, because of its shorter half-life, was not measured in samples collected before Chernobyl and is more useful in identifying Chernobyl fallout. Cesium-134 was below the detection limit in the samples collected on May 12 at BIO, but was readily observable in post-May samples. Cesium-134 was also measured in some samples collected at Point Lepreau. The Cs-134/Cs-137 ratio measured in air particulates in the Point Lepreau area and at Digby, N.S. between May and August decreased from 0.5 to 0.3. The activity ratio measured in terrestrial samples was always less than this ratio (Table 34).

Plots of Cs-134 vs Be-7 and Cs-137 vs Be-7 (Figure 50) for lichen illustrate the use of Cs-134 as a tracer of Chernobyl fallout. Good linear relationships are observed between Cs-134 and Be-7, both for samples collected at Point Lepreau (correlation coefficient, $r = 0.984$) and at BIO ($r = 0.928$). The Cs-134 activities in the arboreal lichen, Usnea, although not shown, also display an excellent linear relationship with Be-7 ($r = 0.937$). Again, the Be-7 normalizes for the deposited air particulate load, correcting for the differences in deposition from location to location. The good linear relationships confirm that the source of the radionuclide is the same, i.e. Chernobyl. The larger slope in the linear regression of Halifax samples is a result of larger amounts of deposition. It has already been observed that the Point Lepreau area has low deposition of air particles compared to Digby and that Halifax has depositional characteristics similar to Digby.

The plot of Cs-137 vs Be-7 (Figure 50) gives a very different picture. The absence of a linear relationship observed is a result of varying residual levels of weapons fallout of Cs-137 for each sample. The Cs-134/Cs-137 ratio can be used to separate the two components of Cs-137. The Cs-134/Cs-137 ratio in lichen is plotted against time in Figure 51. Ratios of 0.25-0.31 are observed during June and decrease thereafter. The percentage of Cs-137 in the lichen which came from Chernobyl can be calculated from the measured Cs-134/Cs-137 ratio in lichen if one estimates the ratio predicted on the basis of Chernobyl inputs. This latter

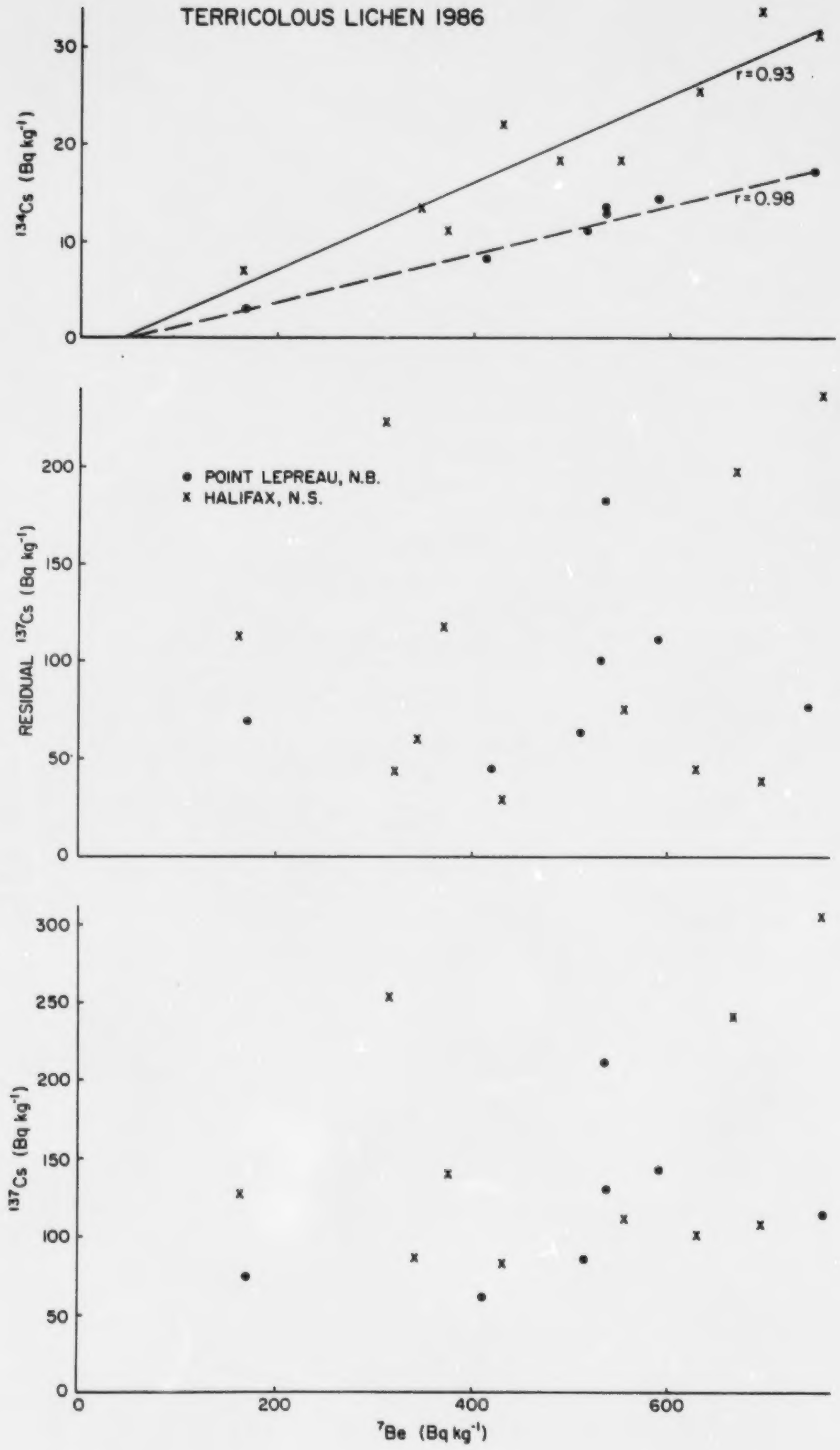


**Figure 50.** Cs-134 versus Be-7 in ground lichen collected at BIO and Point Lepreau; Cs-137 versus Be-7 in gound lichen collected at BIO and Point Lepreau and Cs-137 from Chernobyl versus Be-7 in ground lichen collected at BIO and Point Lepreau.

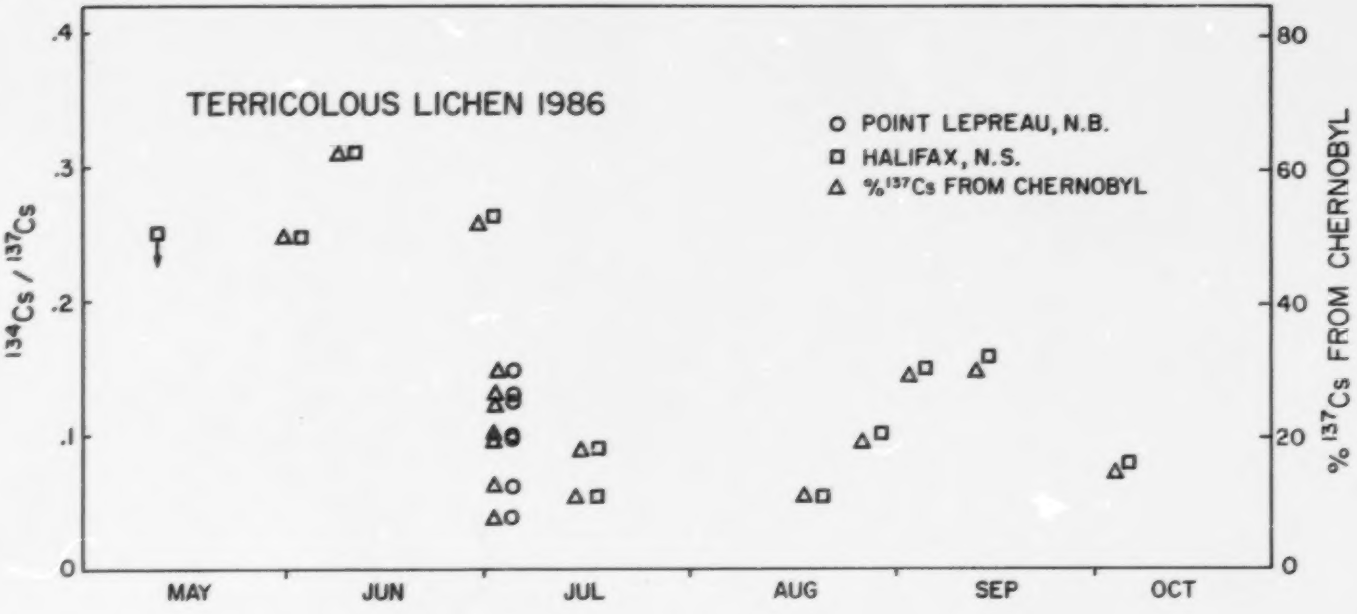


Figure 51. Cs-134/Cs-137 ratios in ground lichen collected in 1986 at BIO and Point Lepreau. Ratios decreased from 0.3 in May to 0.1 in October. The percent Cs-137 from Chernobyl derived from the ratio, is given on the right hand axis and ranges from 60 to 12%.

ratio ($r_{Cher}$) can be calculated using equation 3

$$\%\,^{137}Cs_{Chernobyl} = \frac{measured\ Cs-134/Cs-137\ in\ lichen}{r_{Cher}} \times 100 \qquad (6)$$

$$r_{Cher} = 0.5\, e^{-\lambda eff(^{134}Cs)\,t} / e^{-\lambda eff(^{137}Cs)\,t} \qquad (7)$$

The Chernobyl ratio ($r_{Cher}$) is based on a radioactive half-life of Cs-134 of 2.07y and of Cs-137 of 30.2y, a biological elimination rate of 6.0y (Ellis & Smith, 1987) and a Cs-134/Cs-137 ratio in initial Chernobyl fallout in air of 0.5 (Devell *et al.* 1986). The results from this calculation for BIO lichen and Point Lepreau are displayed in Figure 51. The percentage of Cs-137 in lichen from Chernobyl is higher for the lichen collected at BIO, initially at 52% in May and decreasing to 17% by October, and averaging 32%, while the samples at Point Lepreau averaged 21.3% from Chernobyl. The differences may be a result of several factors;- lower deposition of fallout products from Chernobyl at Point Lepreau, a fact that has already been established, or possibly older lichen from the Point Lepreau area which result in larger proportions of residual Cs-137.

The Cs-137 activities in ground lichen in 1986 at Point Lepreau of 113 Bq/kg are enhanced over previous pre-Chernobyl years; average levels of 119 Bq/kg were found in lichen in 1984 and of 63 Bq/kg in 1985. The average residual level of Cs-137 determined in 1986 lichen of 92 Bq/kg is more appropriate compared to previous measurements.

The average Cs-137 activity in *Usnea* in 1986 at Point Lepreau was found to be 73 Bq/kg. This is a large increase over previous years when average activities were 45 Bq/kg in 1983, 35 Bq/kg in 1984 and 33 Bq/kg in 1985. In addition, *Usnea* collected in the Point Lepreau area has higher ratios of Cs-134/Cs-137 than those of the *Cladonia arbuscula* collected at the same time. An average ratio of 0.202 corresponds to approximately 43 % of the Cs-137 coming from Chernobyl fallout, twice that of the terricolour or ground lichen. *Usnea* has less residual Cs-137 either because its samples are younger than ground lichen, or because the removal rate of cesium from *Usnea* is faster. The calculated percent of residual Cs-137 activity of 56.7% or 41 Bq/kg is comparable to Cs-137 levels from previous pre-Chernobyl years.

Ratios of Cs-134/Cs-137 in sphagnum exhibit a more rapid decrease than in the lichen. This is expected because particles are less effectively trapped by sphagnum and elements are more rapidly removed from the plant. Other plants have low ratios and indicate that uptake of cesium is less active in these plants than in lichen.

### Ru-103

The time dependence of the Ru-103 signal in terrestrial plants reflects that of atmospheric concentrations. Maximum activities were measured in samples collected on June 11, weeks after maximum levels of the other radionuclides were attained much in the same way the atmospheric activities of Ru-103 were maximized several weeks following those of the volatile radionuclides.

The relationship of Ru-103 to Be-7 in lichen is not linear for Point Lepreau or BIO samples (Figure 52) as it was for Cs-134 (Figure 50). In order to identify the differences between the behaviour of Ru-103 and Cs-134, a plot of log (Ru-103/Be-7) with time for BIO was prepared (Figure 53). The Ru-103/Be-7 should correct for differences in deposition rates of atmospheric particles. For comparison, the log (Ru-103 activity) is also plotted. The decrease in the Ru-103/Be-7 ratio with time occurs at a half-life of 26 days ($r=0.9$). An excellent linear regression is also achieved with for Ru-103 data with a slope corresponding to a half-life of 21 days. The similarity in the two curves indicate that there is little difference in the amount of deposition for each sample at BIO. Both half-lives are greater than the half-life for the radioactive decay for Ru-103, so that removal of this radionuclide by biological elimination is important in lichen. The biological half-life is calculated to be 45 days from the Ru-103 data and 75 days for Ru-103/Be-7 data using equation 5. The rapid removal of Ru-103 is consistent with the scatter observed in the plot of Ru-103 vs Be-7 (Figure 52). This rapid

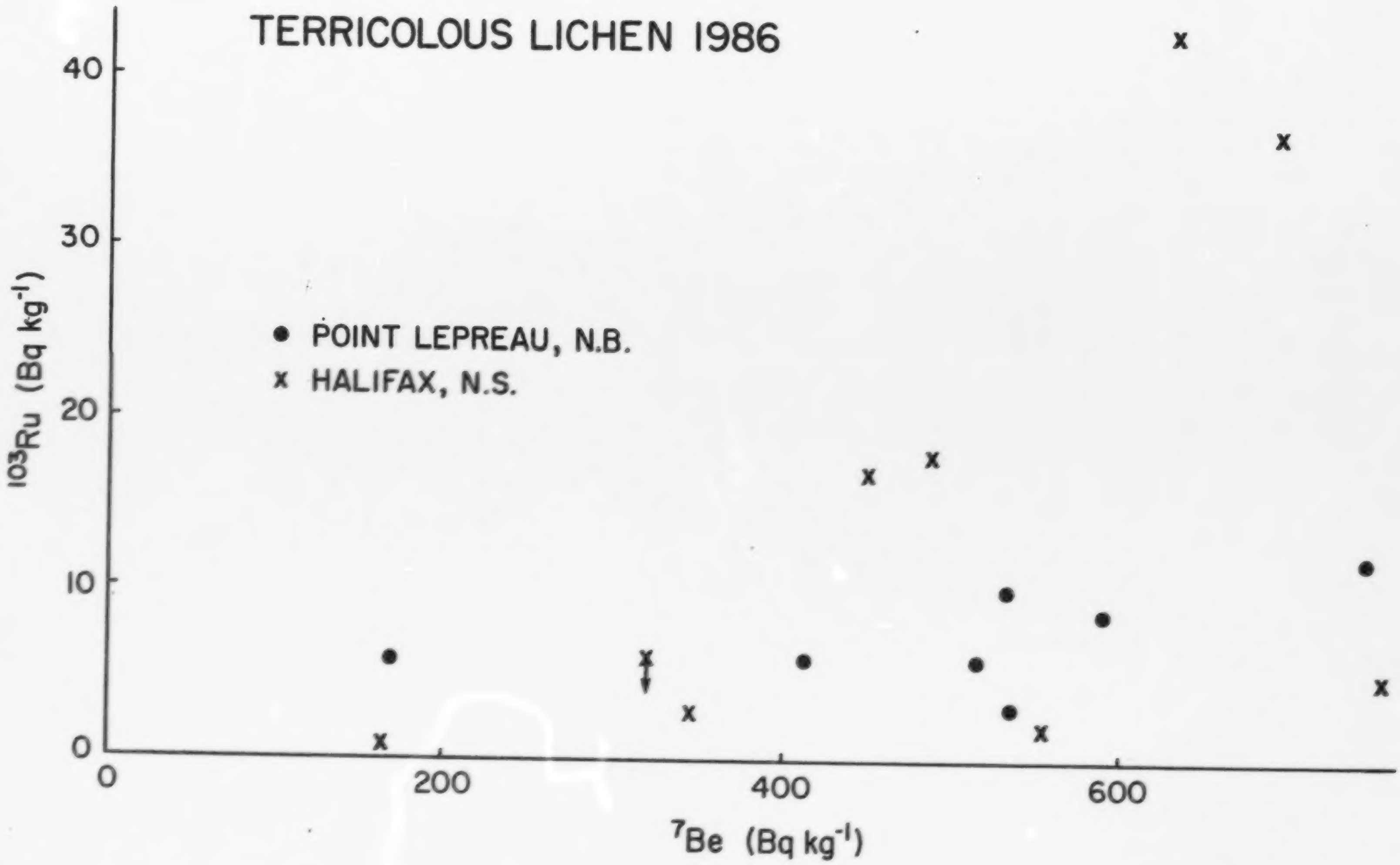


Figure 52. Activities of Ru-103 versus Be-7 in ground lichen collected at BIO and Point Lepreau.

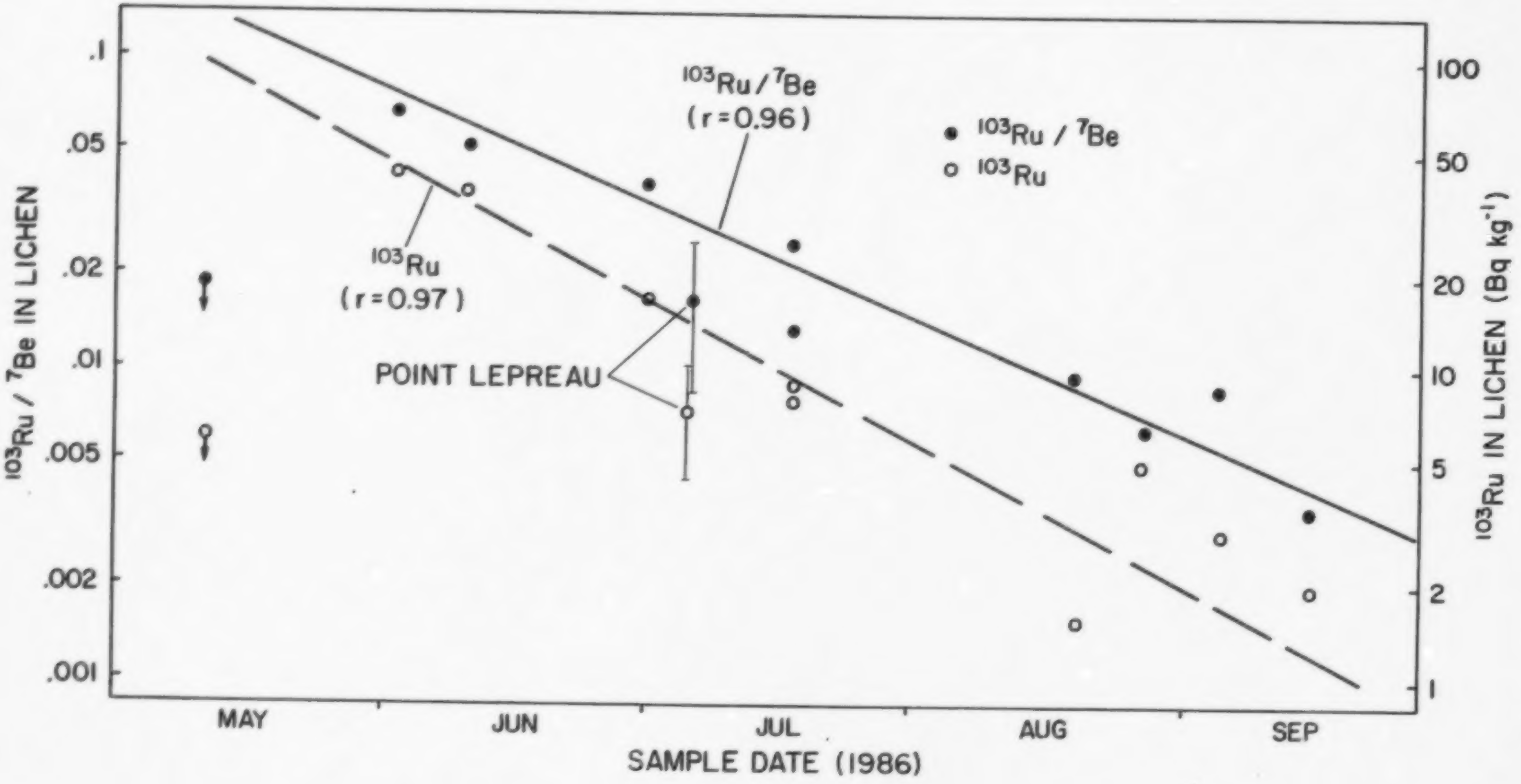


Figure 53. Ru-103/Be-7 ratios in ground lichen versus time for samples collected at BIO and Point Lepreau give a correlation coefficient of 0.97 and a halflife of 21 days.

removal of Ru from lichen has been observed previously (Hanson and Eberhardt, 1971) and is unique for this element because other elements are strongly retained by lichen.

## 7.5 Aquatic plants and animals:

No samples of aquatic plants and animals were collected at BIO. Well water and cistern samples were collected in May, but no fallout radionuclides were measured in these samples, indicating dilution of the contaminated rainwater and/or delays in collection of this water in the wells or cisterns.

Samples were collected in the Point Lepreau area in July (Section 5.1.2) and radionuclide levels are presented in Table 21. Cesium-134 was measured in a few samples and was the only nuclide other than Cs-137 measured which came from Chernobyl. Again, levels of Cs-137 are enhanced by residual levels. Cesium-134 was measured in two plant samples - an equisetum sample with an activity of 7 Bq/kg, resulting in a Cs-134/Cs-137 ratio of 0.58, a water lily sample 13817 with a Cs-134 activity of 4 Bq/kg, and a Cs-134/Cs-137 activity of 0.13, an iris sample (Cs-134 activity of 1 ± 1 Bq/kg and a Cs-134/Cs-137 ratio of 0.07) and in two bullrush samples each with a Cs-134 activity of 3 Bq/kg and Cs-134/Cs-137 ratios of 0.75. The lower ratio measured in the water lily is a result of residual Cs-137. Note that a Cs-137 activity of 45 Bq/kg was measured in a water lily sample collected in 1985. One sample of frog contained measurable Cs-134 at a level of 3 Bq/kg (Table 22). Again, high residual levels of Cs-137 lead to a very small (0.02) Cs-134/Cs-137 ratio.

## 7.6 Plutonium

Although little data is available on the presence of transuranics measured in fallout from Chernobyl, there is some evidence that small amounts of plutonium were released during the accident. Approximately three percent of the plutonium inventory was released (Persson *et al.* 1987) and plutonium was reportedly measured in Great Britain (Webster, 1986).

Samples of air particles, lichen, equisetum and blueberry leaves were analyzed for plutonium and results are presented in Table 35. Because little data is available for levels of plutonium in samples before Chernobyl in the vicinity of Point Lepreau, samples that had been collected before the Chernobyl accident were also selected for analysis.

Levels of plutonium, both Pu-239/240 and Pu-238 were very low in all samples analyzed. Levels in air were below detections limits before and after the Chernobyl event. Activities measured in blueberry leaves and equisetum are very close to the detection limits. Levels in lichen measured after Chernobyl were slightly higher than in samples collected a year earlier in the same location, but were substantially lower than levels measured in the same area in 1981. There is no evidence that plutonium released during the Chernobyl accident was carried to eastern Canada.

Table 35. Plutonium levels in pre- and post-Chernobyl samples.

| Sample Type | Sample # | Sample Date, Location | Pu-239 | Pu-238 | Pu-238 |
|---|---|---|---|---|---|
| | | | mBq/m3 | mBq/m3 | Pu-239 |
| Air | 14528 | May 14-16, 1986<br>Dipper Harbour, NS | <.20 | <.20 | - |
| | 2522 | March 10-17, 1968<br>Dipper Harbour, NS | <.05 | <.05 | - |
| | 14588 | May 15-17, 1986<br>Digby, NS | <.15 | <.15 | - |
| | 2525 | March 17-24, 1986<br>Digby, NS | <.05 | <.05 | - |
| | | | Bq/kg | Bq/kg | |
| Lichen | 81-4651 | July 14, 1981<br>Point Lepreau | 1.19 ± .06 | .041 ± .009 | .034 ± .007 |
| | 81-4653 | July 14, 1981<br>Point Lepreau | .37 ± .03 | .012 ± .005 | .034 ± .014 |
| | 81-4655 | July 14, 1981<br>Point Lepreau | .72 ± .05 | - | - |
| | 81-4659 | July 14, 1981<br>Point Lepreau | .21 ± .03 | .0082 ± .004 | .037 ± .020 |
| | 2087 | July 3, 1985<br>Point Lepreau | .16 ± .02 | .002 ± .001 | .011 ± .007 |
| | 1 3849 | July 5, 1986<br>Point Lepreau | .10 ± .01 | .005 ± .001 | .055 ± .021 |
| | 13588 | July 2, 1986<br>BIO | .06 ± .01 | .002 ± .001 | .017 ± .010 |
| Equisetum | 2100 | July 3, 1985<br>Point Lepreau | <.002 | .002 ± .001 | - |
| | 13822 | July 5, 1986<br>Point Lepreau | .008 ± .005 | .005 ± .002 | - |
| Blueberry leaves | 2492 | July 3, 1985<br>Point Lepreau | .005 ± .002 | .005 ± .002 | - |
| | 13835 | July 5, 1986<br>Point Lepreau | .002 ± .001 | .003 ± .002 | - |
| | 13591 | July 16, 1986<br>B.I.O. | <.002 | <.002 | - |

## 7.7 Conclusions

(1) Radionuclides derived from the Chernobyl accident were detected in most samples collected after the event in the Point Lepreau, N.B., and Halifax, N.S., areas. Nuclides detected were Cs-137, Cs-134, Cs-136, I-131, Ru-103, Te-132, I-132, and La-140.

(2) Fallout products from Chernobyl were first measured in eastern Canada in air samples collected May 7-9. Air concentrations peaked on May 9-11, and gradually decreased to below detection limits by mid-June. A second plume containing elevated levels of Ru-103 and a smaller proportion of particulate I-131 arrived in eastern Canada on May 16-18. Deposition of fallout from Chernobyl was greater at Digby, N.S. and Halifax, N.S. than at Point Lepreau, N.B.

(3) Iodine-131 activities were the highest of the measured fallout products. Maximum concentrations in air were 31.8 mBq/m$^3$, in milk 1.57 Bq/1, in lichen 104 Bq/kg and in seaweed 29.1 Bq/kg (wet). Seventy percent of I-131 in air was in the gaseous phase decreasing slightly with time.

Iodine-131 removal from plants occurred totally by radioactive decay.

(4) Beryllium-7 air concentrations proved useful as indicators of amounts of air particulate matter loads and were used to normalize air concentrations at different locations for differences in air particle concentration. Beryllium-7 was also useful in normalizing for uptake of air particles by lichen. Good linear relationships between Be-7 and Cs-134 proved to be most useful in identifying and quantifying Chernobyl fallout.

(5) Cesium-134/Cs-137 ratios of 0.45 were measured in initial air samples and decreased to 0.30 by mid-June as a result of radioactive decay and temporal changes in releases from Chernobyl.

(6) Residual levels of Cs-137 were calculated using the Cs-134/Cs-137 ratios and contributed 32% to the Cs-137 signal in ground lichen at Halifax, N.S, 21% in

ground lichen at Point Lepreau, N.B., and 43% in arboreal lichen at Point Lepreau. Differences are a result of different amounts of fallout, age of lichen and efficiency in trapping air particles.

(7) Ruthenium is a less volatile element and was released at a later stage in the Chernobyl accident and its behaviour in the atmosphere may be different from the other volatile fallout products. As a result, Ru-103 arrived weeks later and its distribution was different compared to those of other fallout products. Ruthenium is rapidly removed from lichen with a biological half-life in the order of 75 days.

(8) There was no evidence for the presence of plutonium in fallout from Chernobyl in eastern Canada.

## 8.0 LABORATORY INTERCOMPARISON PROGRAM

The AERU laboratory participates in a "blind" laboratory intercomparison study provided by the United States Environmental Protection Agency (EPA) in order to maintain a check on the laboratory's analytical precision and accuracy in radionuclide results (Laboratory #1A). The wide range of radionuclide material provided by the EPA is matched for each geometry and matrix used to ensure routine check on all analytical results. This material is also used to check on the internally used standards and blanks. The results of the program are published and distributed to participants throughout United States and Canada by the EPA.

The AERU results for the period 1979 to 1982, are reported in Ellis *et al.* (1984) and Nelson *et al.* (1985). The AERU results for 1984 are reported in Nelson *et al.* (1986). Values determined by AERU are generally within 2 standard deviation of the EPA's reported values. Tritium in water, Cs-137 in air filters, Sr-90 and I-131 in water are consistently in good agreement with EPA values. As a result of postal delays, some of the short-lived radioisotopes in the mixed gammas in water were below detection limits. However, longer lived radioisotopes showed good results in the same medium. The analysis of Pu-239 and Ra-226 in water was added in 1984 as a result of new analysis carried out in the AERU laboratory. Radium-226 results agreed well with EPA values. The initial Pu-239 analysis revealed a tracer calibration error, which resulted in a low value of Pu-239 in water. This error was corrected and the subsequent analysis gave excellent agreement with the EPA value. The results indicate that there has been no significant problems existing with experimental procedures and operations. Values determined by AERU are generally in good agreement with EPA values (Table 36).

Table 36. Results of AERU laboratory intercomparison experiments with the Environmental Protection Agency

| Sample Matrix | Collection Date | Nuclide | EPA Value | AERU Value | Grand Mean | AERU SD | All Labs SD | AERU/ EPA |
|---|---|---|---|---|---|---|---|---|
| Air Filter | Mar. 29/85 | Cs-137 | 6 | 5 | 6.83 | 1 | 1.64 | 0.83 |
| Air Filter | Aug. 30/85 | Cs-137 | 8 | 8 | 9.42 | 1 | 2.03 | 1.0 |
| Air Filter | Apr. 25/85 | Cs-137 | 10 | 11.7 | 11.48 | 1 | 2.13 | 1.17 |
| Water | Mar. 14/85 | H-3 | 5227 | 5161 |  | 87 | 523 | 0.99 |
| Water | Jun. 13/85 | H-3 | 3125 | 3167 | 3052 | 21 | 347 | 1.04 |
| Water | Oct. 17/85 | H-3 | 5973 | 5679 | 5693 | 65 | 406 | 0.95 |
| Water | Feb. 18/85 | Co-60 | 20 | 20 | 19 | 2 | 3 | 1.0 |
| Water | Feb. 18/85 | Zn-65 | 55 | 46 | 56 | 3 | 6 | 0.84 |
| Water | Feb. 18/85 | Cs-134 | 35 | 38 | 33 | 3 | 4 | 1.09 |
| Water | Feb. 18/85 | Cs-137 | 25 | 26 | 25 | 1 | 25 | 1.04 |
| Water | Jun. 7/85 | Cr-51 | 44 | 45 | 48 | 7.5 | 10.7 | 1.02 |
| Water | Jun. 7/85 | Co-60 | 14 | 12 | 15 | 1 | 2.7 | 0.86 |
| Water | Jun. 7/85 | Zn-65 | 47 | 45 | 49 | 4 | 6.2 | 0.96 |
| Water | Jun. 7/85 | Ru-106 | 62 | 65 | 58 | 15 | 12 | 1.05 |
| Water | Jun. 7/85 | Cs-134 | 35 | 28 | 33 | 1 | 4 | 0.8 |
| Water | Jun. 7/85 | Cs-137 | 20 | 19 | 21 | 3 | 3 | 0.95 |
| Water | Apr. 19/85 | Co-60 | 15 | 13 | 16 | 2.5 | 2.7 | 0.87 |
| Water | Apr. 19/85 | Cs-134 | 15 | 11 | 15 | 1.2 | 3.0 | 0.73 |
| Water | Apr. 19/85 | Cs-137 | 12 | 12 | 13 | 1.5 | 2.5 | 1.0 |
| Water | Jun. 27/85 | Co-60 | 10 | 12 | 10 | 1.2 | 2 | 1.2 |
| Water | Jun. 27/85 | Cs-134 | 5 | 3 | 5 | 0.6 | 1.3 | 0.6 |
| Water | Jun. 27/85 | Cs-137 | 5 | 7 | 6 | 0.6 | 1.2 | 1.4 |
| Water | Jan. 11/86 | Pu-239 | 16 | 15 | 15 | 0.1 | 1.2 | 0.94 |
| Food Slurry | Jan. 25/86 | I-131 | 35 | 33 | 35 | 4 | 5.4 | 1.07 |
| Food Slurry | Jan. 25/86 | Cs-137 | 29 | 31 | 31 | 1.5 | 4.1 | 1.05 |
| Food Slurry | Jan. 31/86 | I-131 | 20 | 21 | 21 | 4.7 | 2.4 | 1.3 |
| Food Slurry | Jan. 31/86 | Cs-137 | 15 | 19 | 17 | 4.4 | 1.8 | 1.2 |
| Water | Sep. 12/86 | Ra-226 | 6 | 7 | 6 | 0.2 | 1.1 | 1.2 |

## 9.0 CONCLUSIONS

1) 1985 and 1986 were the third and fourth years of operation for the Point Lepreau NGS. Emissions from the plant as monitored by the LEM showed a decrease in the total activity released each year. Increases in the amounts of Zn-65, Sr-90 and Ag-110 m were noted while releases of Mn-54 and Cr-51 decreased.

2) A single cruise was undertaken in December of 1985. The average Cs-137 activity was $3.2 \pm 0.4$ Bq/ℓ and the range in H-3 activities was $<2.0$ to 3.6 Bq/ℓ with the majority of seawater samples analyzed being below the detection limit. There was no evidence of increased Cs-137 or H-3 levels in the Bay of Fundy due to NGS activity.

3) During 1985/86 three separate thermal plume surveys were undertaken in the vicinity of the NGS. Results of the spring survey in 1985 showed that under certain conditions it was possible for the effluent from the outfall to be trapped at the bottom resulting in increased exposure of benthic populations to plant effluent.

A second study undertaken during Cruise 85-041 in December 1985 took place under conditions of very little salinity stratification, where, as a result, the thermal plume was restricted to the surface and elevated temperatures were observed only near the surface close to the outfall.

4) Average tritium levels in air moisture on the peninsula of Point Lepreau continued their upward trend. Average H-3 levels in 1985 were $26 \pm 33$ and in 1986 were $45 \pm 78$ Bq/ℓ. Tritium levels at the AMS in Musquash showed an increase above background levels for the first time while the AMS at Digby, N.S. remained at background levels.

5) Levels of fallout radionuclides measured in air particulate material were below AERU detection limits for 1985. Samples collected in 1986 contained several radionuclides originating from the Chernobyl nuclear accident.

6) Levels of radionuclides found in marine systems showed no increase over pre-operational levels for 1985. Samples collected in 1986 showed increases in Cs-137 and Cs-134 over 1985 and were the result of inputs from the Chernobyl accident.

7) Levels of radionuclides measured in aquatic and terrestrial animal and plant samples show no increase over pre-operational levels for 1985. Radionuclide levels increased in 1986 as a result of input from the Chernobyl accident.

8) Tritium levels in plant and freshwater samples collected showed an increase over pre-operational levels reflecting enhanced releases from the NGS.

9) A field trip was organized in February of 1986 in response to a boiler tube leak of heavy water. Increases in the amount of H-3 released to both the air and ocean were noted in the LEM and SEMP. Terrestrial samples collected during this field trip contained levels of tritium at levels as great as 550 Bq/ℓ at maximum. No radionuclides released from the reactor (with the exception of H-3) were measured in the freshwater samples collected.

(10) The arrival of fallout products from Chernobyl to eastern Canada and their distributions were adequately observed and measured using the present Point Lepreau monitoring program. Results are in good agreement with results in Canada and other countries. This indicates that the present monitoring program is appropriate, flexible, and is capable of expansion to monitor emergencies etc. quickly.

## ACKNOWLEDGEMENTS

The working group on Point Lepreau Environmental Monitoring is composed of scientists from different government departments, (Appendix 1) all of whom have contributed to the development of this program. In particular, we wish to thank Gary Bugden (Bedford Institute of Oceanography) who supervised the physical oceanographic component of this program and B.L. Beattie (Atmospheric Environmental Service, Bedford, N.S.) who supervised the meteorological aspects of PLEMP. Equally helpful have been K. Brown, W. Sexsmith and K. Hughes, (Environment New Brunswick, Fredericton, N.B.) who have supervised much of the marine, terrestrial and aquatic sampling, and B. Johnson (Canadian Wildlife Service, Sackville, N.B.) who supervised the bird sampling. In addition, Mia Huh, J. Abriel, and G. Folwarczyna have provided substantial analytical support in the AERU laboratory analysing samples for Pb-210, Cs-137, Pu and H-3 and Dr. J.M. Bewers, (Bedford Institute of Oceanography) has provided continual support and many helpful discussions throughout all stages of this program.

Residents of Point Lepreau, N.B. who have provided great assistance in the operation of the air monitoring stations include Mr. and Mrs. G. Thompson (Dipper Harbour), Mrs. J. Pollock (Musquash) and Mr. R. Mawhinney (Welch Cove) while Mr. M. Durkee has kindly provided similar support in the operation of an air monitoring station at Digby, N.S. Appreciation is also extended to those members of the N.B. Electric Power Commission's Health Physics Department who helped with the deployment and operation of air monitoring station equipment, notably Dr. J. Paciga, Mr. C. Nason and Mr. J.C. McCulley, and James O'Donnell and Dr. J. Paciga for their assistance in setting up and carrying out the thermal plume surveys.

## REFERENCES

AARKROG, A. (1985) *"Bioindicator Studies in Nordic waters"*. NKA report REK-5B, 74 pp.

ADAMS, L.W., PETERLE, T.J. and WHITE, G.C. (1979) Tritium behaviour in aquatic plants and animals in a freshwater marsh ecosystem. In: *Behaviour of Tritium in the Environment*, IAEA, Vienna, 711 pp.

AOYAMA, M., HIROSE, K., SUZUKI, Y., INOUE, H. and SUGIMURA, Y. (1986) High level radioactive nuclides in Japan in May. Nature, 321, 819-820.

APSIMON, H. and WILSON, J. (1986) Tracking the cloud from Chernobyl. New Scientist, 42-45.

BEATTIE (1987) Personal Communication.

BISHOP, F.J., ELLIS, K., SMITH, J.N. and BEWERS, J.M. (1980) Pre-operational environmental monitoring report for the Point Lepreau, N.B. nuclear generating station. Bedford Institute of Oceanography Report Series - BI-R-80-1.

BONDIETTI, E. A. and BRANTLEY, J. N. (1986) Characteristics of Chernobyl radioactivity in Tennessee. Nature, 322, 313-314.

BOWEN, H. J. M. (1979) Environmental Chemistry of the Elements, Acedemic Press, London, 333 pages.

BUMPUS, D.F. and LAUZIER, L.M. (1965) Surface circulation on the continental shelf off eastern North America between Newfoundland and Florida. Folio 7, Serial Atlas of the Marine Environment.

COUGHTREY, P. J., JACKSON, D. and THORNE, M. C. (1983) Iodine in domestic animals and man. In Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems, A Critical Review of Data. Vol. 3, 341-357.

COUGHTREY, P.J. and THORNE, M.C. (1983) *Radionuclide distribution and transportation in terrestrial and aquatic ecosystems: a critical review of data*, A.A. Balkema, Rotterdam.

CSONGOR, E., KISS, A. Z., NYAKO, B. M. and SOMORJAI, E. (1986) Chernobyl fallout in Debrecen, Hungary. Nature, 324, 216.

DAVIS, J. J. (1963) Cesium and its relationship to potassium in ecology. In: Radioecology, Schultz, V. and Klement, A. W. Jr., Eds., Reinhol, New York, 539.

DEVELL, L., TOVEDAL, H., BERGSTROM, U., APPELGREN, A., CHYSSLER, J. and ANDERSSON, L. (1986) Initial Observations of fallout from the reactor accident at Chernobyl. Nature, 321, 192-193.

ELLIS, K., NELSON, R.W.P., and SMITH, J.N. (1984) Pre-operational environmental monitoring report for the Point Lepreau, N.B. nuclear generating station - 1982. Can. Tech. Rep. Hydrogr. Ocean Sci. 43: vi + 173 p.

ELLIS, K. M. and SMITH, J. N. (1987) Dynamic model for radionuclide uptake in lichen. J. Envir. Radioactivity, 5, 185-208.

FRY, F. A., CLARKE, R. H. and O'RIORDAN, M. C. (1986) Early estimates of UK radiation doses from the Chernobyl reactor. Nature, 321, 193-195.

GOYAL, R. and SEAWARD, M.R.D. (1981) Lichen ecology of the Scunthorpe Heathlands., II Industrial metal fallout pattern from lichen and soil assays. Lichenologist 13 (3): 289-300.

GUIMARAES, J.R.D. and PENNA-FRANCA, E. (1985) Cs-137, Co-60 and I-125 bioaccumulation by seaweeds from the Angra dos Reis Nuclear Power Plant region. Marine Environment Research 16, 77-93.

HALE, M.E. (1973) Growth. In *The Lichen*, ed Ahmadjian, V. and Hale, M.E., Academic Press, N.Y., 472-492.

HANSON, W.C. (1967) Radioecological concentration processes characterizing Arctic ecosystems. In: *Radioecological Concentration Processes*, Aberg, B. and Hungate, F.P., Eds., Pergamon Press, New York, 675 pp.

HANSON, W.C. and EBERHARDT, L.L. (1971) Cycling and compartmentalizing of radionuclides in the northern Alaskan lichen communities. USAEC, COO-2122-5 Memorial Institute Pacific Northwest Laboratory, Ecosystems Department, Battelle, Richland, WA.

HARRISON, F.L., and KORANDA, J.J. (1971) Tritiation of aquatic animals in an experimental freshwater pool. 3rd National Symp. on Radioecology, Oak Ridge, California University, Lawrence Radiation Laboratory, Rep. UCRL-72930 (1971).

HARLEY, N., FISENNE, I., ONG, L.D. AND HARLEY, J.H. 1965. Fission yield and fission product decay. USAEC Health Safety Lab. Fallout Program Quart. Summ. Rep. HASL-264, 251-260.

HEALTH AND WELFARE CANADA (1986) Environmental Radioactivity in Canada 1986. Environmental Health Directorate, Department of Health and Welfare, Ottawa, Rept. # 87-EHD136.

HILL, C. R., ADAM, I., ANDERSON, W., OTT, R. J. and SOWBY, F. D. (1986) Iodine-131 in human thyroids in Britain following Chernobyl. Nature, 321, 655-656.

IAEA (1985a) *"Sediment KD's and concentration factors for radionuclides in the marine environment."* IAEA, Vienna, 1985, 73 pp.

IAEA (1985b) *"Behaviour of radionuclides released into coastal waters.* "IAEA Vienna, 1985, 183 pp.

IAEA (1981) *"Tritium in some typical ecosystems".* IAEA, Vienna, 1981, 117 pp.

IMANAKA, T., and KOIKE, H. (1986) Fallout in Japan from Chernobyl. J. Envir. Radioactivity, 4, 149-153.

KRISHNASWAMI, S., BENNINGER, L.K., ALLER, R.C. and VON DAMM, K.L. (1980) Atmospherically-derived radionuclides as tracers of sediment mixing and accumulation in nearshore marine and lake sediments: evidence from Be-7, Pb-210 and Pu-239,240. Earth Planet. Sci. Lett., 47, 307-318.

KRISNAMOORTHY, T.M., IYENGAR, T.S., and SOMAN, S.D. (1975) Behaviour of tritium in the plant domain. In: *"Behaviour of Tritium in the Environment"*, IAEA and NEA Symp. Proc. San Francisco, Oct. 1978, 623-634.

KUPFERMAN, S.L., LIVINGSTON, H.D. and BOWEN, V.T. (1979) Mass balance for Cs-137 and Sr-90 in the North-Atlantic Ocean. J. Mar. Res., 37, 157-199.

KWAPULINSKI, J., SEAWARD, M.R.D. and BYLINSKA, E.A. (1985) Cs-137 content of *Umbilicaria* species with particulate reference to altitude. The Science of the Total Environment, 41, 125-133.

LAL and PETERS (1967) Cosmic ray produced radioactivity on the earth, in Handbuch der Physik, K. Sitte, Ed. (Springer, Berlin), 46, 2, 551.

LARSEN, R., SANDERSON, C. G., RIVERS, W. and ZAMICHIELI, M. (1986) The characterizaion of radionuclides in North American and Hawaiian surface air and deposition following the Chernobyl accident. Environment Measurements Laboratory-460, 1-104.

MILLER, D.S., and BRIGHOUSE, B.A. (1984) *Thermal Discharges*, BHRA, 221 pp.

MOGHISSI, A.A., BRETTHAUER, E.W. and CAMPTON, E.H. (1973) Separation of water from biological and environment samples for tritium analyses. Anal. Chem. 45 (8), 1565-6.

MURPHY, C.E. Jr., PENDERGAST, M.M. (1975) Environmental transport and cycling of tritium in the vicinity of atmospheric releases. In *Behaviour of Tritium in the Environment*, IAEA and NEA. Symp. Proc., San Francisco, Oct. 1978, 623-634.

NATIONAL RESEARCH COUNCIL CANADA (1983) *"Radioactivity in the Canadian Aquatic Environment"* NRCC, Ottawa, 290 pp.

NBEPC (1985) Point Lepreau Generating Station Quarterly Technical Report, Fourth Quarter 1985, PLGS-QTR-4-85.

NBEPC (1986) Point Lepreau Generating Station Quarterly Technical Report, Fourth Quarter 1985, PLGS-QTR-4-86.

NELSON, R.W.P., ELLIS, K. and SMITH, J.N. (1985) "Environmental monitoring report for the Point Lepreau, N.B., nuclear generating station - 1983" Can. Tech. Rep. Hydrogr. Ocean Sci., 59: v + 146 pp.

NELSON, R.W.P., ELLIS, K. and SMITH, J.N. (1986) "Environmental monitoring report for the Point Lepreau, N.B. nuclear generating station-1984" Can. Tech. Rep. Hydrogr. Ocean Sci., No. 75 vi + 154 p.

NELSON, D. (1981) Personal Communication.

NISHIZAMA, K., TAKATA, K., HAMADA, N., OGATA, S., YAMASHITA, O., OHSHIMA, M. and KAYAMA, Y. (1986) Iodine-131 in milk and rain after Chernobyl. Nature, 324, 308.

PASQUILL, F. and SMITH, F.B. (1983) *Atmospheric Diffusion*, Ellis Horwood Limited, New York, 437 pp.

PERSSON, C., RODHE, H. and DE GEER, L. (1987) The Chernobyl Accident - A Meteorological Analysis of How Radionuclides Reached and were Deposited in Sweden. Ambio, 16, 20-31.

PRINGLE, D. M., VERMEER, W. J., and ALLEN, K. W. (1986) Gamma-ray spectrum of Chernobyl fallout. Nature, 321, 569.

RICE, T.R. and BAPTIST, J.P. (1974) Geologic effects of radioactive emissions from nuclear power plants. In: *Human and Ecologic Effects of Nuclear Power Plants*, Sagan, L.A. ed. Thomas Books, Springfield, 536 pages.

SAVADIVAN, S. and MISHRA, U.C. (1986) Radioactive fallout swipe samples from Chernobyl. Nature, 324, 23-24.

SMITH, J.N., ELLIS, K. and BISHOP, F.J. (1981) Pre-operational environmental monitoring report for the Point Lepreau, N.B. nuclear generating station - 1980. Bedford Institute of Oceanography Report Series - BI-R-81-10.

SMITH, J.N., ELLIS, K. and BISHOP, F.J. (1982) Pre-operational environmental monitoring report for the Point Lepreau, N.B. nuclear generating station - 1981. Can. Tech. Rept. of Hyd. and Oc. Sci. 4: vi + 194 p.

SUTHERLAND, J.K. (1986) Environmental radiation monitoring data for Point Lepreau generating station January 01, 1985 to December 31, 1985. Health Physics Department Report, NBEPC, Report HP-07000-86-1.

SUTHERLAND, J.K. (1987) Environmental radiation monitoring data for Point Lepreau generating station January 01, 1986 to December 31, 1986. Health Physics Department Report, NBEPC, Report HP-07000-87-1.

THOMAS, A. J. and MARTIN, J. M. (1986) First assessment of Chernobyl radioactive plume over Paris. Nature, 321, 817-819.

WEBSTER, D. (1986) How ministers misled Britain about Chernobyl. New Scientist, 1529, 43-46.

## Appendix 1

### Members of the Working Group on Point Lepreau Environmental Monitoring

| | |
|---|---|
| BEWERS, J.M. | (Chairman): Chemical Oceanography Division, Atlantic Oceanographic Laboratory, Bedford Institure of Oceanography, P.O. Box 1006, Dartmouth, N.S. B2Y 4A2 |
| BROWNE, K.W. | Environment Services Branch, Environment New Brunswick, P.O. Box 6000, Fredericton, N.B. E3B 5H1 |
| BUGDEN, G. | Coastal Oceanography Division, Atlantic Oceanographic Laboratory, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, N.S. B2Y 4A2 |
| NEUMEYER, R. | Environmental Protection Service, Atlantic Region, Fifth Floor, Queens Square, 45 Alderney Drive, Dartmouth, N.S. B2Y 2N6 |
| ELLIS, K.M. | Chemical Oceanography Division, Atlantic Oceanography Laboratory, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, N.S. B2Y 4A2 |
| HARDING, G. | Marine Ecology Laboratory, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, N.S. B2Y 4A2 |
| JOHNSON, B. | Canadian Wildlife Service, Environment Canada, P.O. Box 1570, Sackville, N.B. E0A 3C0 |
| MEYERHOF, D. | Chief, Environmental Radiation Hazards Division, Radiation Protection Bureau, Health and Welfare Canada, 775 Brookfield Road, Ottawa, Ontario K1A 1C1 |
| SCARRATT, D.J. | Department of Fisheries and Oceans, 1707 Lower Water Street, Box 550, Halifax, N.S. B3J 2S7 |
| SCHAFER, C.T. | Atlantic Geoscience Centre, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, N.S. B2Y 4A2 |
| SMITH, J.N. | Atlantic Environmental Radiation Unit, Chemical Oceanography Division, Atlantic Oceanography Laboratory, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, N.S. B2Y 4A2 |
| BEATTIE, B.L. | Scientific Services Meteorologist, Atlantic Region, Atmospheric Environment Service, 1496 Bedford Highway, Bedford, N.S. B4A 1E5 |

## Appendix 2

Conversion factors for different radioactivity units.

1 Becquerel (Bq) = 2.7 x $10^{-11}$ Curies (Ci)

1 Bq = 27 pCi

1 Bq = 60 dpm

1 Bq/l = 8.3 Tritium Units (TU)

1 Ci = 3.7 x $10^{10}$ Bq

1 mCi = 3.7 x $10^{7}$ Bq

1 psCi = 3.7 sx $10^{-2}$ Bq

1 dpm = 0.0167 Bq

1 dpm = 0.45 pCi

1 TU = 0.12 Bq/l

1 TU = 7.2 dpm/l

1 TU = 3.2 pCi/l

# Appendix 3

Detection limits (Bq/kg) for each radionuclide and geometry assuming a counting time of $10^5$ s for analyses performed one month subsequent to sample collection. Detection limit for specific sample is determined by choosing detection limit for a radionuclide for the appropriate geometry and dividing by the sample weight. These estimates are approximate and will vary depending upon the specific counting times and delay between sample collection and analysis.

| Nuclide | Half-life | Geometry 1 | Geometry 2 | Geometry 3 | Geometry 4 | Geometry 5 |
|---|---|---|---|---|---|---|
| Ag-110 m | 253.0 d | 150 | 94 | 95 | 95 | 47 |
| Ba-140 | 12.8 d | 1700 | 1700 | 1000 | 1000 | 490 |
| Be-7 | 53.6 d | 1100 | 1200 | 690 | 670 | 370 |
| Ce-141 | 32.4 d | 280 | 330 | 170 | 140 | 110 |
| Ce-144 | 284.0 d | 780 | 900 | 460 | 400 | 200 |
| Co-56 | 77.0 d | 130 | 140 | 90 | 90 | 40 |
| Co-57 | 270.0 d | 110 | 130 | 63 | 54 | 35 |
| Co-58 | 71.0 d | 130 | 140 | 77 | 78 | 39 |
| Co-60 | 5.26 y | 120 | 120 | 65 | 69 | 35 |
| Cr-51 | 28.0 d | 1700 | 1800 | 1100 | 1001 | 570 |
| Cs-134 | 2.07 y | 110 | 120 | 69 | 69 | 33 |
| Cs-137 | 30.2 y | 107 | 100 | 62 | 60 | 31 |
| Eu-152 | 12.5 y | 660 | 690 | 410 | 410 | 200 |
| Eu-155 | 1.81 y | 300 | 340 | 160 | 160 | 69 |
| Fe-59 | 44.6 y | 340 | 330 | 190 | 200 | 89 |
| I-131 | 8.06 d | 1200 | 1400 | 780 | 750 | 410 |
| La-140 | 40.2 h | 510 | 510 | 340 | 360 | 190 |
| Mn-54 | 313.0 d | 110 | 110 | 67 | 65 | 31 |
| Nb-95 | 35.1 d | 180 | 180 | 110 | 110 | 54 |
| Ru-103 | 39.6 d | 150 | 160 | 93 | 92 | 46 |
| Ru-106 | 1.0 y | 900 | 940 | 540 | 550 | 250 |
| Sb-124 | 60.2 d | 18 | 20 | 11 | 11 | 6 |
| Sb-125 | 2.7 y | 240 | 260 | 150 | 147 | 73 |
| Zn-65 | 244.0 d | 290 | 260 | 140 | 150 | 73 |
| Zr-95 | 64.0 d | 140 | 240 | 150 | 150 | 70 |

## Appendix 4

Detection limits (Bq/kg) for each radionuclide and geometry assuming a counting time of $10^5$ s for analyses performed one year subsequent to sample collection.

| Nuclide | Half-life | Geometry 1 | Geometry 2 | Geometry 3 | Geometry 4 | Geometry 5 |
|---|---|---|---|---|---|---|
| Ag-110 m | 253.0 d | 380 | 410 | 240 | 240 | 120 |
| Ba-140 | 12.8 d | - | - | - | - | - |
| Be-7 | 53.6 d | - | - | - | - | - |
| Ce-141 | 32.4 d | - | - | - | - | - |
| Ce-144 | 284.0 d | 1700 | 2000 | 1000 | 890 | 660 |
| Co-56 | 77.0 d | 2600 | 2800 | 1600 | 1600 | 750 |
| Co-57 | 270.0 d | 250 | 300 | 150 | 140 | 82 |
| Co-58 | 71.0 d | 3400 | 3400 | 1900 | 1900 | 980 |
| Co-60 | 5.26 y | 130 | 130 | 74 | 78 | 40 |
| Cr-51 | 28.0 d | - | - | - | - | - |
| Cs-134 | 2.07 y | 150 | 160 | 93 | 940 | 45 |
| Cs-137 | 30.2 y | 110 | 110 | 63 | 61 | 32 |
| Eu-152 | 12.5 y | 700 | 720 | 440 | 430 | 200 |
| Eu-155 | 1.81 y | 420 | 480 | 220 | 230 | 98 |
| Fe-59 | 44.6 y | 57000 | 56000 | 32000 | 30000 | 15000 |
| I-131 | 8.06 d | - | - | - | - | - |
| La-140 | 40.2 h | - | - | - | - | - |
| Mn-54 | 313.0 d | 230 | 230 | 140 | 135 | 65 |
| Nb-95 | 35.1 d | - | - | - | - | - |
| Ru-103 | 39.6 d | 49000 | 53000 | 31000 | 3000 | 15000 |
| Ru-106 | 1.0 y | 1700 | 1800 | 1000 | 1000 | 470 |
| Sb-124 | 60.2 d | 800 | 880 | 500 | 490 | 250 |
| Sb-125 | 2.7 y | 300 | 330 | 180 | 180 | 91 |
| Zn-65 | 244.0 d | 730 | 680 | 370 | 383 | 190 |
| Zr-95 | 64.0 d | 7900 | 8200 | 4900 | 4900 | 2400 |